SYSTEMS EFFECTIVENESS

COMPILED BY

SYSTEMS EFFECTIVENESS BRANCH

OFFICE OF NAVAL MATERIAL

January 1965

DEFINITION OF SYSTEM EFFECTIVENESS

SYSTEM EFFECTIVENESS —A MEASURE OF THE EXTENT TO WHICH A SYSTEM CAN BE EXPECTED TO COMPLETE ITS ASSIGNED MISSION WITHIN AN ESTABLISHED TIME FRAME UNDER STATED ENVIRONMENTAL CONDITIONS.

FOREWARD

The main purpose of this pamphlet is to provide to personnel of the Naval Material Support Establishment (NMSE) a collection of papers in a single volume which reflect the attitude and philosophy of the Chief of Naval Material towards various aspects of systems effectiveness. It also provides a discussion of the planning, design, and cost considerations in system development as well as some techniques now being utilized in the NMSE in order to realize the development of effective systems.

The majority of the papers included in this pamphlet were presented by the Chief of Naval Material and his representatives at the Northeastern States, Navy Research and Development Clinic held 18-20 Nov 1964 in Philadelphia. Several other papers which were presented to other audiences were also considered appropriate for inclusion in this pamphlet.

This publication has been reviewed and approved in compliance with SECNAVINST 5600.16.

E A Ruckner

Rear Admiral E. A. Ruckner, USN
Deputy Chief of Naval Material for
Development/Chief of Naval Development

Man Parameters in System Support

- CDR Keith N. Sargent, USN
  Head, Systems Effectiveness Branch
  Office of Naval Material

Other ONM Presentations

The Key to Development Pay-Off

- Rear Admiral E. A. Ruckner, USN
  Deputy Chief of Naval Material for
  Development/Chief of Naval Development

System Effectiveness Assurance Management

- Dr. Leslie W. Ball
  Director of Reliability, Aero-Space Division
  Boeing Aircraft Corporation

Systems Effectiveness - A Tool for Appraisal

- CDR Keith N. Sargent, USN
  Head, Systems Effectiveness Branch
  Office of Naval Material

Systems Effectiveness - Navy

- CDR Keith N. Sargent, USN
  Head, Systems Effectiveness Branch
  Office of Naval Material

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Northeastern States Navy R&D Clinic
Philadelphia, Pennsylvania
18-19-20 November 1964
Presentations

EXCERPTS EXTRACTED FROM UNCLASSIFIED DIGEST OF

FUTURE NAVY WEAPONS AND SUPPORT SYSTEMS

REMARKS OF

VICE ADMIRAL W. A. SCHOECH, USN

AT THE

NORTHEASTERN STATES

NAVY RESEARCH AND DEVELOPMENT CLINIC

PHILADELPHIA, PENNSYLVANIA

18 NOVEMBER 1964

To this point I have been suggesting specific areas of effort, each of which would be of interest to certain of you in attendance here. I would like now to focus your attention very briefly on an area of effort in which all of you can participate. In fact -- it is an area in which everyone participating in Navy R&D contracts will be involved. I speak of the area which we term Systems Effectiveness.

In this era of complex combinations of men and machines, Systems Effectiveness, and its fiscal corollary, Cost Effectiveness, constitute the most important area of concern to military R&D Management. It is, or soon will be, of equal import to civilian R&D Management which addresses itself to military systems.

What does this mean to you?

It means that Systems Effectiveness, which we define as a measure of the extent to which a system can be expected to complete its assigned mission within an established time frame under stated environmental conditions, is the focus of our research and development efforts. It means that Systems Effectiveness is the measure of the goodness of our systems. Systems Effectiveness is thus a matter of paramount concern to us, and to you.

The manager, the scientist and the engineer, working toward the development of a system, must take into account all of the attributes of the system which we refer to as qualitative characteristics. Such factors as reliability, maintainability, operability, logistic supportability, human factors and all the other factors affecting the goodness of a system, must be thoroughly considered in development planning.

It is quite true that each of the characteristics which I have mentioned have been considered to varying degrees as factors in existing weapon systems. What is needed is correlated consideration of all of these characteristics in systems design. Only by providing in the early developmental stages for reliability, maintainability, simplicity, supportability and similar factors can the systems you develop bear up under Systems Effectiveness analysis.

Your participation in this effort will, I believe, be in two separate areas. The first will be the further detailed development of Systems Effectiveness methodology, techniques and model structures. The second will be the application of this discipline to your proposals.

We can no longer afford the "build one and try it" approach with a subsequent "get well" effort to patch on reliability, maintainability, value engineering and the like. We cannot afford to develop systems using men as multi-purpose gap-fillers between machine interfaces. Neither can we accept weapons systems which must be staffed by crews of PHD's. We must develop mathematical modeling techniques with which to do our systems engineering homework. These models cannot be achieved without a cohesive discipline within which they can be structured. This discipline we term Systems Effectiveness. In the highly complex weaponry of modern warfare, this discipline is absolutely necessary.

There is one additional thought I would like to leave with you. In reading newly issued Specific Operational Requirements, I have repeatedly observed a much needed and increasing emphasis on the position and role of human engineering in the new weapons systems.

These systems are often thought of, and rightly, as combined man-machine systems. The Navy will continue to be composed both of machines and of people. It is increasingly necessary that the weapons and support systems of the future properly blend the capabilities and the limitations of the man with those of the machine. The day is past when the man can be regarded as an entity apart from the machine. He is explicitly a part of the weapons system, and he contributes to its effectiveness those capabilities which are uniquely his. Systems effectiveness must take into account the man who operates the system, and the personal reactions of people. Of all the scientific contributions yet to be made to the defense of the country, it is probable that among the most valuable will be contributions from the life sciences, particularly the behavioral science groups.

In conclusion, I'm sure you will agree that it will be interesting to see, in the decade following 1975, how closely our prognostications fit reality. But whatever the future holds it is certain that the Navy will remain an important national security force, its roles and missions relatively unchanged, but its weapons and tactical methods greatly affected by burgeoning technologies.

It has been said that the wars of the future will be won in the laboratory. I suspect that the security of our country ten to twenty years from now will depend in large part on the ability of all of us here today — military and civilian — to master the expanding technologies which can ultimately spell triumph or tragedy for the United States and the free world.

ANALYTICAL TECHNIQUES IN SYSTEM DESIGN

(excerpt)

by LeRoy Rosen

Program Manager of FRISCO in the

Bureau of Ships

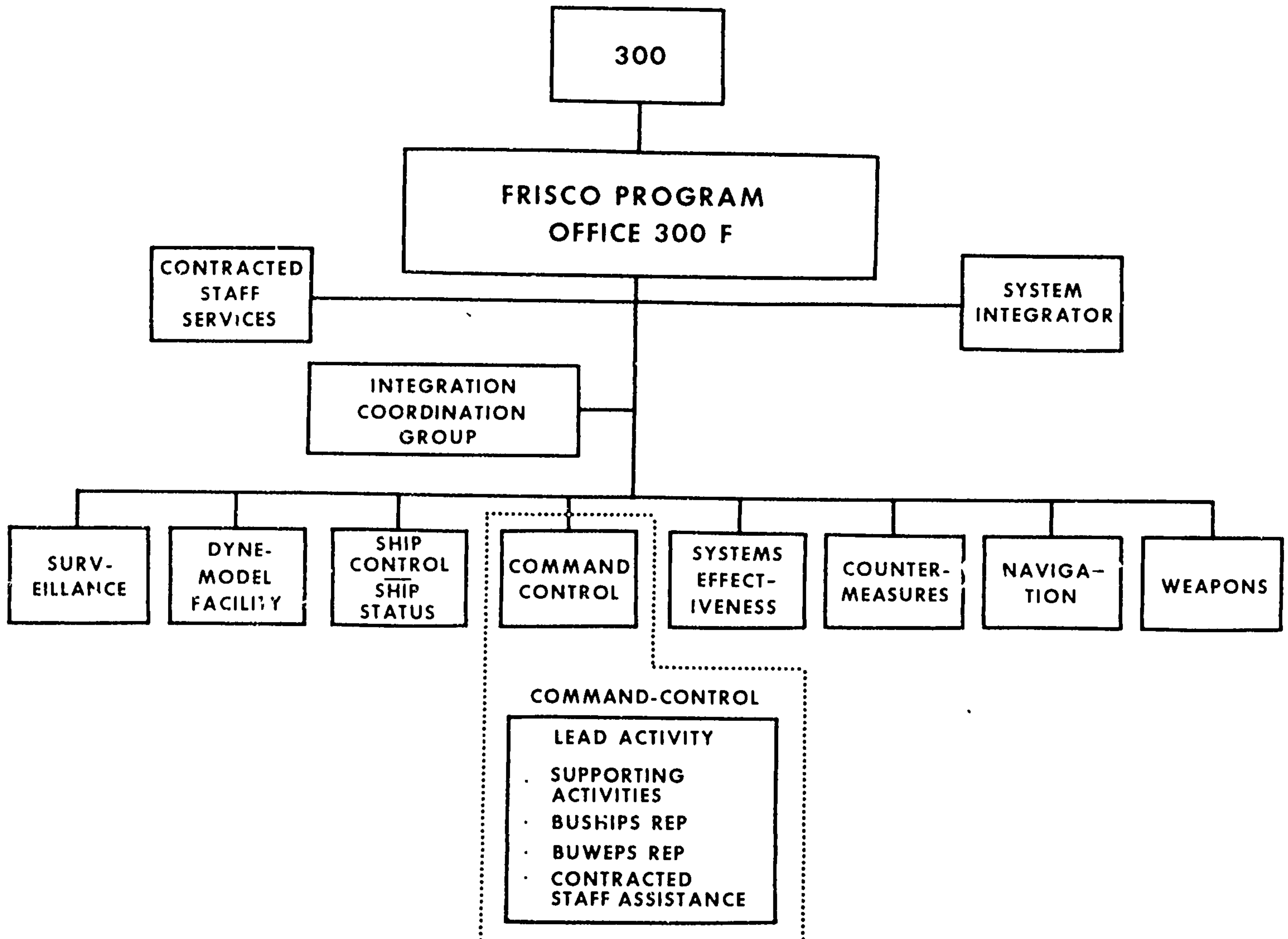
The organization required to handle a program that encompasses so many disciplines as does FRISCO is a special one. Figure 1 shows the various functions that must be coordinated under the Program Office. No single contractor or Navy laboratory has ever performed the entire design of a submarine tactical control system. Therefore it has been necessary to organize the Navy laboratories to work on this task, with each participating in areas concerning its own specialty. These laboratories are dispersed around the country, so that good communications among them and with the Program Office is extremely important in achieving the project objectives. Hence, a special set of tools is required to perform a system integration in which various parts of the system are being developed at geographically dispersed locations. To FRISCO's knowledge, there were no tools available in industry that could be utilized for technical management. PERT is a useful tool for scheduling and estimating costs for a system but the main concern of FRISCO are tools to insure the technical goals of a system and it was these which were lacking.

The approach that FRISCO derived to meet this problem requires the accompanying series of steps. The tasks shown above the dotted line, in Figure 2, are the responsibility of the Program Office. Those below the line are the responsibility of the laboratories and/or contractors.

Through these procedures, the impact of the given threats and missions of the nuclear attack submarine is determined. The information on the threat and mission is obtained from the appropriate sections of the Navy but this must be translated into technological requirements for men and equipments.

The entire environment in which a submarine can be expected to

FRISCO ORGANIZATION



ASSURANCE MANAGEMENT

FIGURE 1

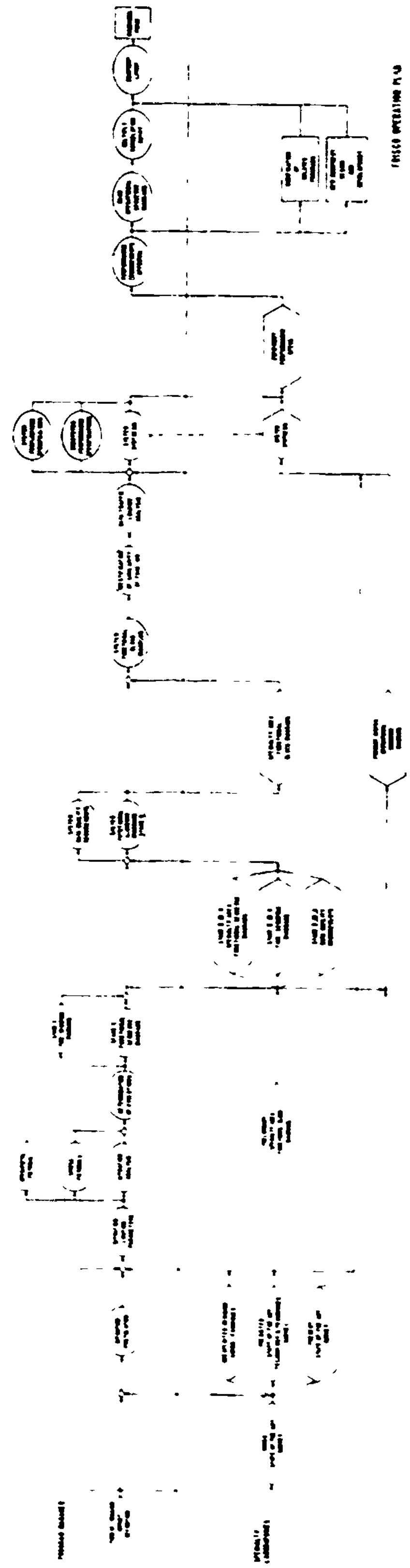


FIGURE 2

operate is far too complex to study exhaustively. Therefore, a number of tactical models have been postulated to represent various elements of the complete environment. It is expected that by studying each of these models in detail and then summing over the requirements generated by each, the overall system design goals can be identified. By an appropriate selection of models, a reasonable picture of the entire system should be obtained.

There are seven variables that must be considered in formulating a tactical model (Figure 3). These are: mission, area, force mix, political situation, physical situation, technological assumptions, and tactics.

"Missions" include such types of operations as ASW, minelaying, and the sinking of surface ships. "Area" takes into account the geography of the location in which the operation occurs and identifies restricted or unrestricted areas, deep or shallow water, etc. The "force mix" is stated for both own and enemy ship, indicating whether either is alone or operating in combination with other submarines, surface ships or aircraft. The "political situation" -- cold war, nuclear, non-nuclear war -- is important as it is reflected in the tactics that the submarine and its target employs. The "physical situation" points out the physical details of the chosen area. This includes water temperature, current, salinity, thermal layers, etc. It is important to choose an actual location where such data are available to insure that all the people working on the program are using the same set of conditions. The "technological assumptions" describe what the enemy's capabilities are anticipated to be in the time scale under consideration. The last variable, "tactics", involves

VARIABLES TO BE CONSIDERED IN THE TACTICAL MODEL

I MISSIONS:

II AREA:

III FORCE MIX:

IV POLITICAL SITUATION:

V PHYSICAL SITUATION:

VI TECHNOLOGICAL ASSUMPTIONS:

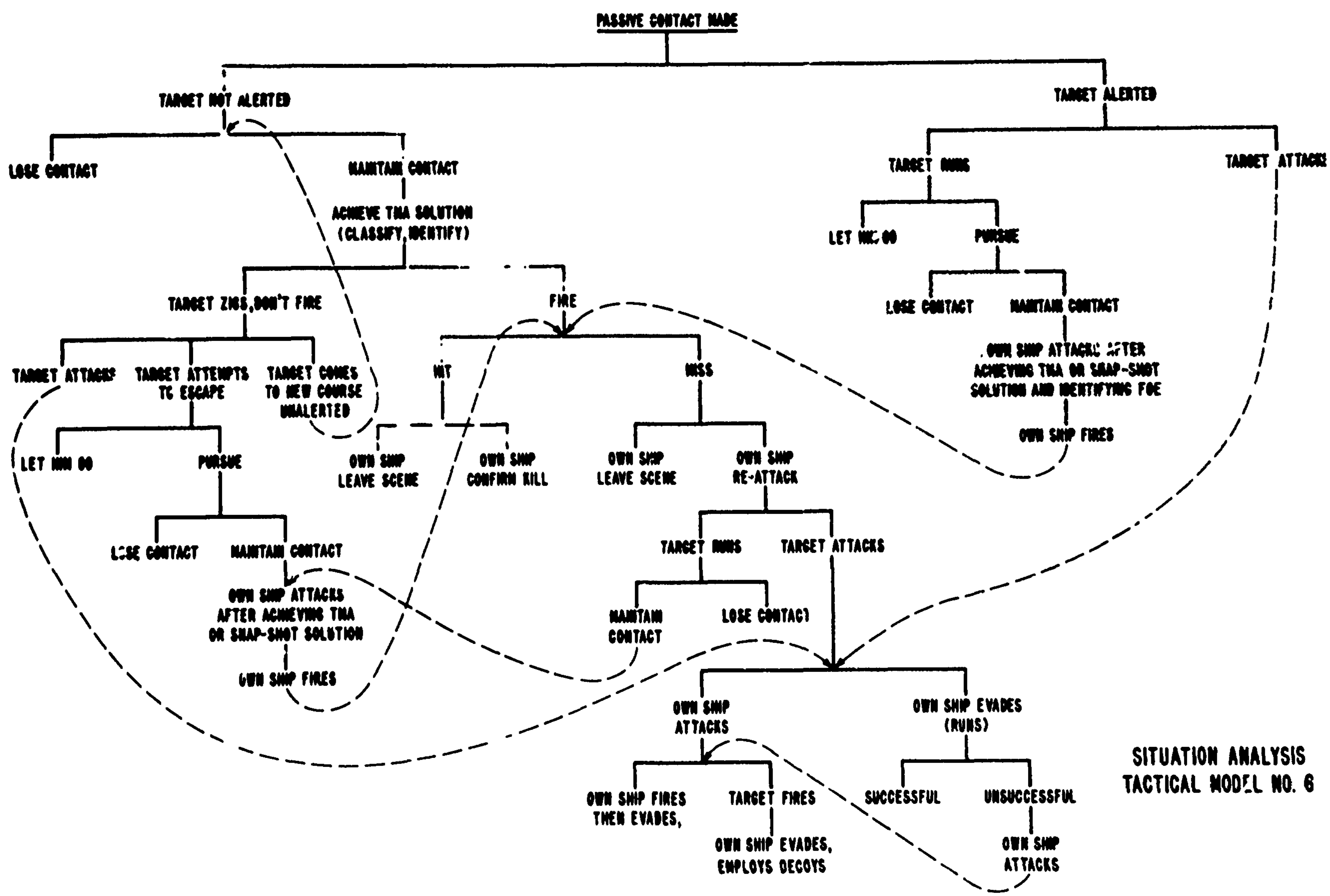
VII TACTICS:

FIGURE 3

a new concept since at the present, tactics are generated from the optimal usage of existing equipments. FRISCO is dealing with new equipments; it should therefore be recognized that tactics should be dynamically evolving with the possible choices of equipments. However, this is not the domain of the technical side of the Navy's organization. Therefore, it is necessary to coordinate closely with operational divisions to keep them well informed of technical developments.

Each of the seven variables affects the information flow within the submarine and is therefore important in the determination of the required functional information flow that must be provided in the optimized system to satisfy the threat and mission requirements. Once the variables to be considered have been identified in the tactical model, the laboratories can perform a state-of-the-art survey to determine the technological capabilities that will be available in the given time period. This provides limiting parameters to the tactical models indicating where the submarine's performance must be constrained by the state-of-the-art.

The next step is to embark on a situation analysis of each tactical model as shown in Figure 4. This analysis starts with the basic hypotheses of the model and then treats the various alternatives that could occur. In the model described previously, the start of the evolution occurs when contact between the two submarines is made. For such a case the target can have been alerted or not. If alerted, it can attack or evade. In any case, own ship can either maintain or lose contact, attack or track, etc. The various tie-ins between the alternatives are indicated by the dashed lines. Most of the major alternatives must be treated if the system design is to be optimized



PASSIVE CONTACT MADE
TARGET NOT ALERTED
TARGET ALERTED
LOSE CONTACT
MAINTAIN CONTACT
ACHIEVE TMA SOLUTION (CLASSIFY, IDENTIFY)
TARGET ZIGS, DON'T FIRE
FIRE
TARGET ATTACKS
TARGET ATTEMPTS TO ESCAPE
TARGET COMES TO NEW COURSE UNALERTED
HIT
MISS
LET HIM GO
PURSUE
OWN SHIP LEAVE SCENE
OWN SHIP CONFIRM KILL
OWN SHIP LEAVE SCENE
OWN SHIP RE-ATTACK
LOSE CONTACT
MAINTAIN CONTACT
OWN SHIP ATTACKS AFTER ACHIEVING TMA OR SNAP-SHOT SOLUTION
OWN SHIP FIRES
TARGET RUNS
TARGET ATTACKS
MAINTAIN CONTACT
LOSE CONTACT
OWN SHIP ATTACKS
OWN SHIP EVADES (RUNS)
OWN SHIP FIRES THEN EVADES,
TARGET FIRES
OWN SHIP EVADES, EMPLOYS DECOYS
SUCCESSFUL
UNSUCCESSFUL
OWN SHIP ATTACKS
TARGET RUNS
TARGET ATTACKS
LET HIM GO
PURSUE
LOSE CONTACT
MAINTAIN CONTACT
OWN SHIP ATTACKS AFTER ACHIEVING TMA OR SNAP-SHOT SOLUTION AND IDENTIFYING FOE
OWN SHIP FIRES
SITUATION ANALYSIS
TACTICAL MODEL NO. 6

FIGURE 4

for a maximum number of situations.

After situation analyses have been performed, two types of pictorials are brought into use, operational and stress. The operational pictorial (Figure 5) is a picture of the situation first described in the tactical model then made dynamic in the situation analysis. It is based on sound operational doctrine derived from what is normally done when confronted with a certain situation. This is useful in observing system operation under normal conditions. However, equipment designers are concerned with stress situations in which various alternatives can be considered to determine what particular course of action produces the maximum stress in technical capabilities of the different subsystems. For example, firing a certain weapon at its maximum range places certain requirements on the performance or accuracies of the ship control, navigation, and sonar subsystems. Similarly, there will be situations which place extreme demands on ship control (avoidance of broaching), navigation (under ice navigating), and each of the other subsystems aboard the submarine. These stress situations may all be different and each one must be studied. These situations are displayed by stress pictorials.

At this point functional sequence diagrams (FSD's), such as shown in Figure 6, are produced. These diagrams are intended to isolate the major functions which are performed on the submarine, without consideration of equipments or personnel, and trace the information flow among them so that it is possible to observe how the functions are coordinated in performing a given job. The functional titles on the FSD's are initially drawn at a gross level, e.g., weapon

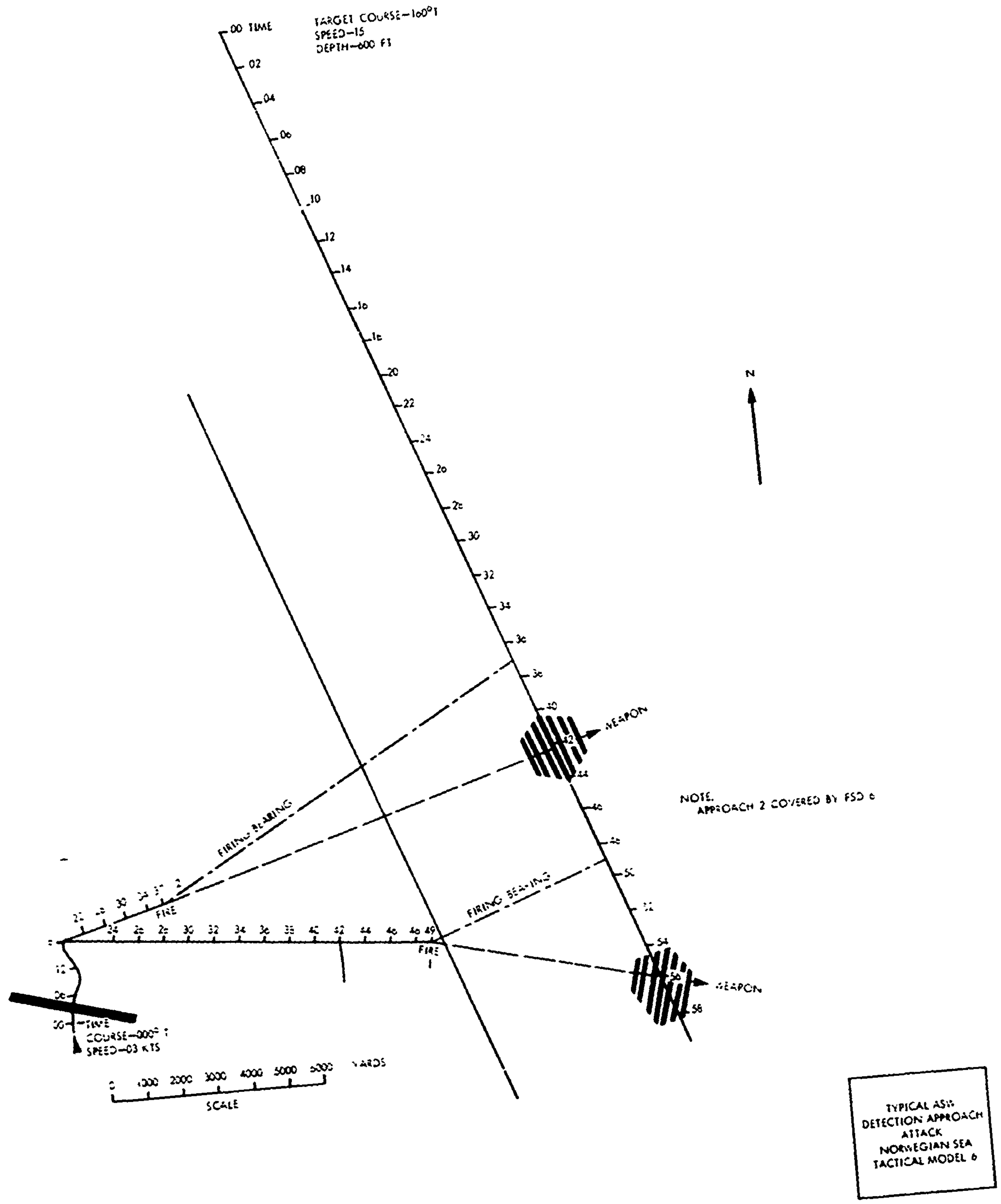

TARGET COURSE—160°T
SPEED—15
DEPTH—600 FT
00 TIME
FIRING BEARING
FIRE
WEAPON
NOTE.
APPROACH 2 COVERED BY FSD 6
N
TIME
COURSE—000° T
SPEED—03 KTS
YARDS
0 1000 2000 3000 4000 5000 6000
SCALE
TYPICAL ASW
DETECTION APPROACH
ATTACK
NORWEGIAN SEA
TACTICAL MODEL 6

FIGURE 5

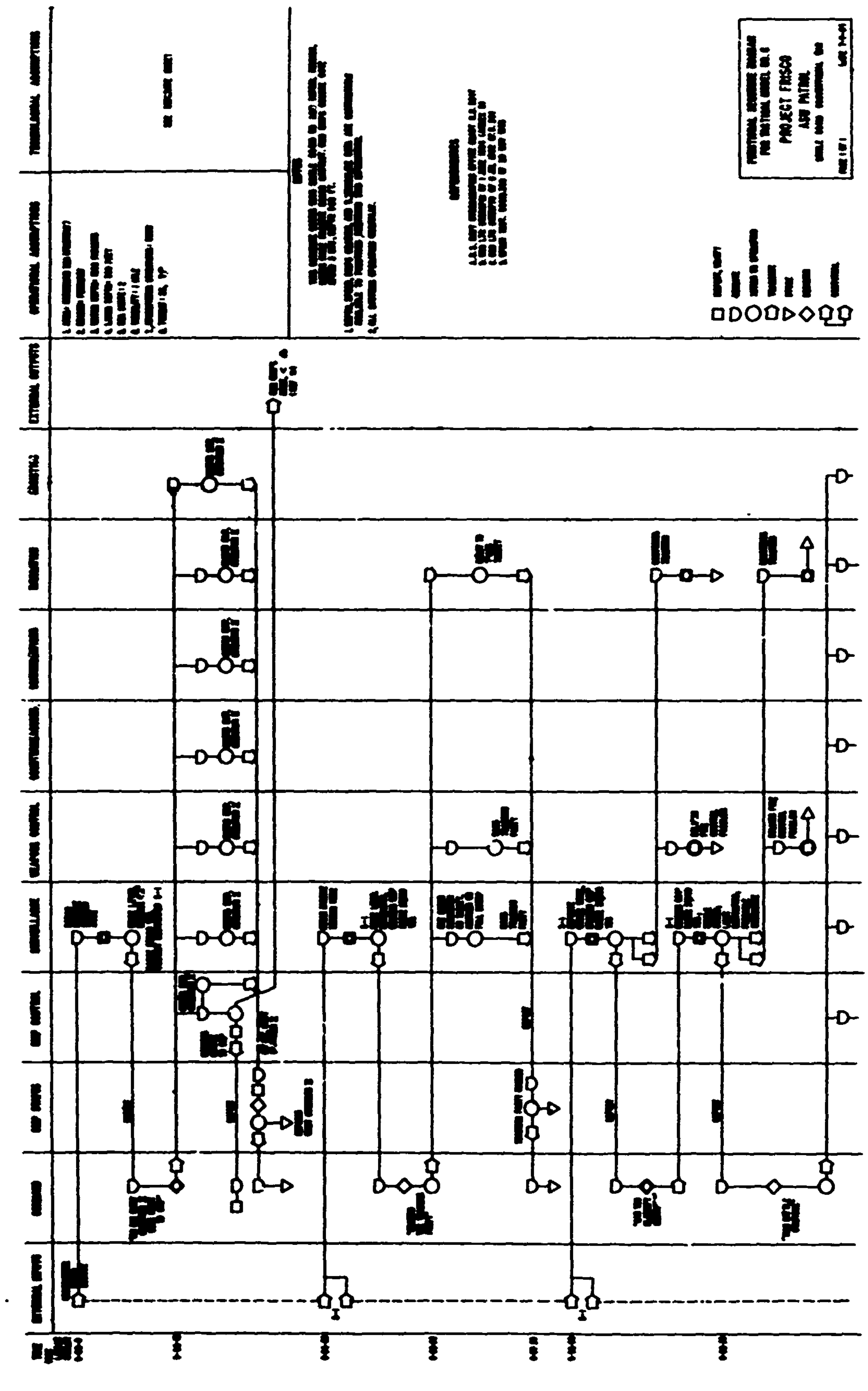


FIGURE 6

control, surveillance, countermeasures. These titles correspond to the assignments of specialty areas to the Navy laboratories. Using the FSD's, the personnel in a given laboratory can see what is expected of them in the areas assigned to their responsibility and also can gain an understanding as to the relationship of their specialty to those of other labs. With this tool, they gain an understanding of how information generated within a given area is used in another area.

Upon receiving this gross first level FSD, the personnel at each laboratory produce a second level FSD (Figure 7) to identify in greater detail the relationships between subfunctions contained within a given function. For example, the ship control column can be subdivided into such subfunctions as course control, speed control, depth control, and ballast control. It would be the job of the ship control laboratory to relate these subfunctions so as to meet the functional goals.

Each of the subfunctions can be further subdivided into lower levels of detail as illustrated for depth control in Figure 8. This subdividing process continues until the lowest meaningful level of subdivision, called the n^{th} level, is reached.

At the lower levels of detail, it becomes possible for the specialists at the laboratories to assign specific values to the performance or accuracies of the elements in the subsystem based on the tactical situation under study. For example, in a given situation where the submarines diving planes must be positioned to establish a trim angle, it may be necessary to establish the trim angle to an accuracy of $\pm$ 0.5 degrees. For another situation the required angle might be quite different. This type of data is summed in the "data quality" column for all postulated situations, to see what the actual values required of ship

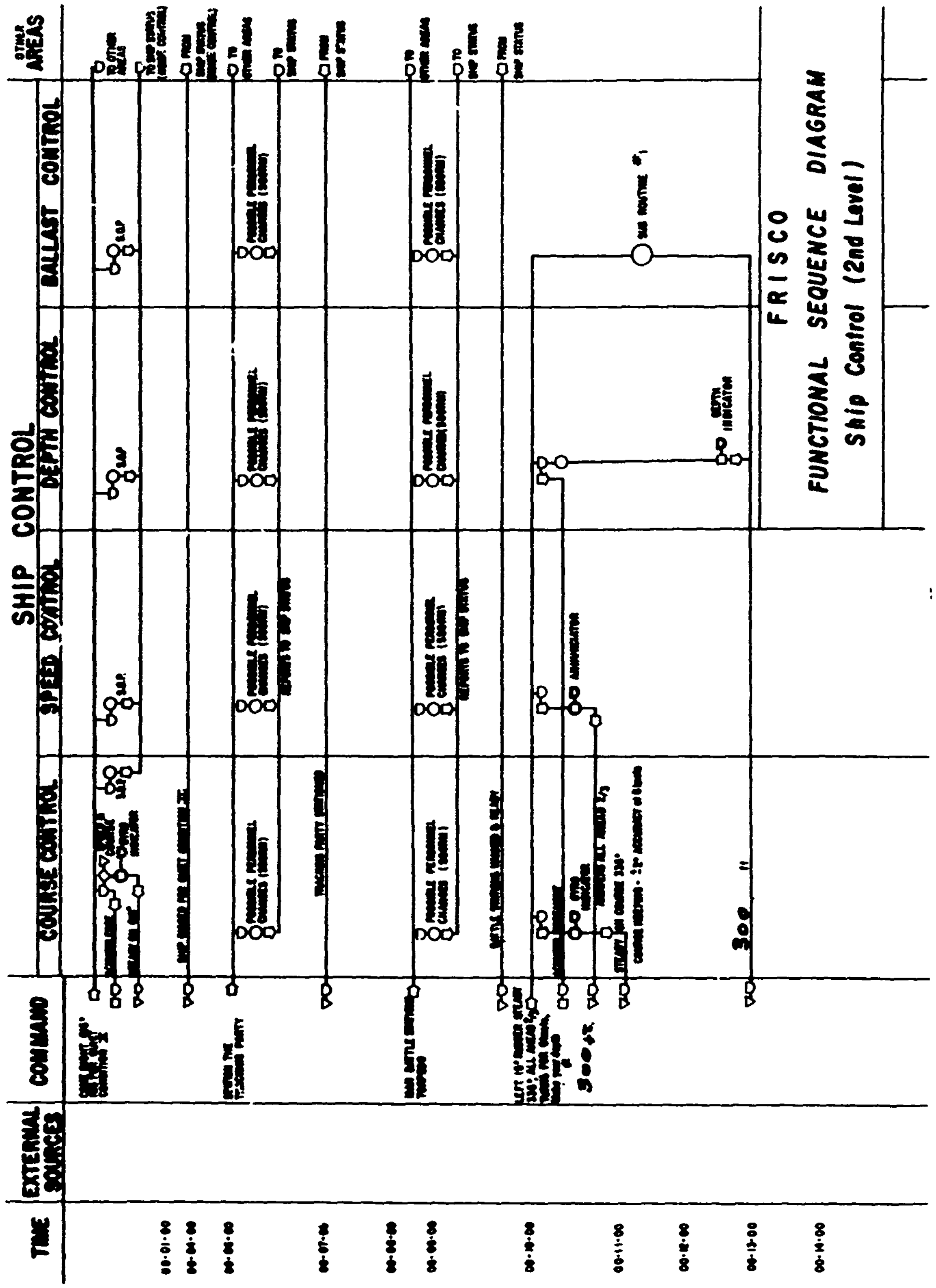

SHIP CONTROL
TIME
EXTERNAL SOURCES
COMMAND
COURSE CONTROL
SPEED CONTROL
DEPTH CONTROL
BALLAST CONTROL
OTHER AREAS
FRISCO
FUNCTIONAL SEQUENCE DIAGRAM
Ship Control (2nd Level)

FIGURE 7

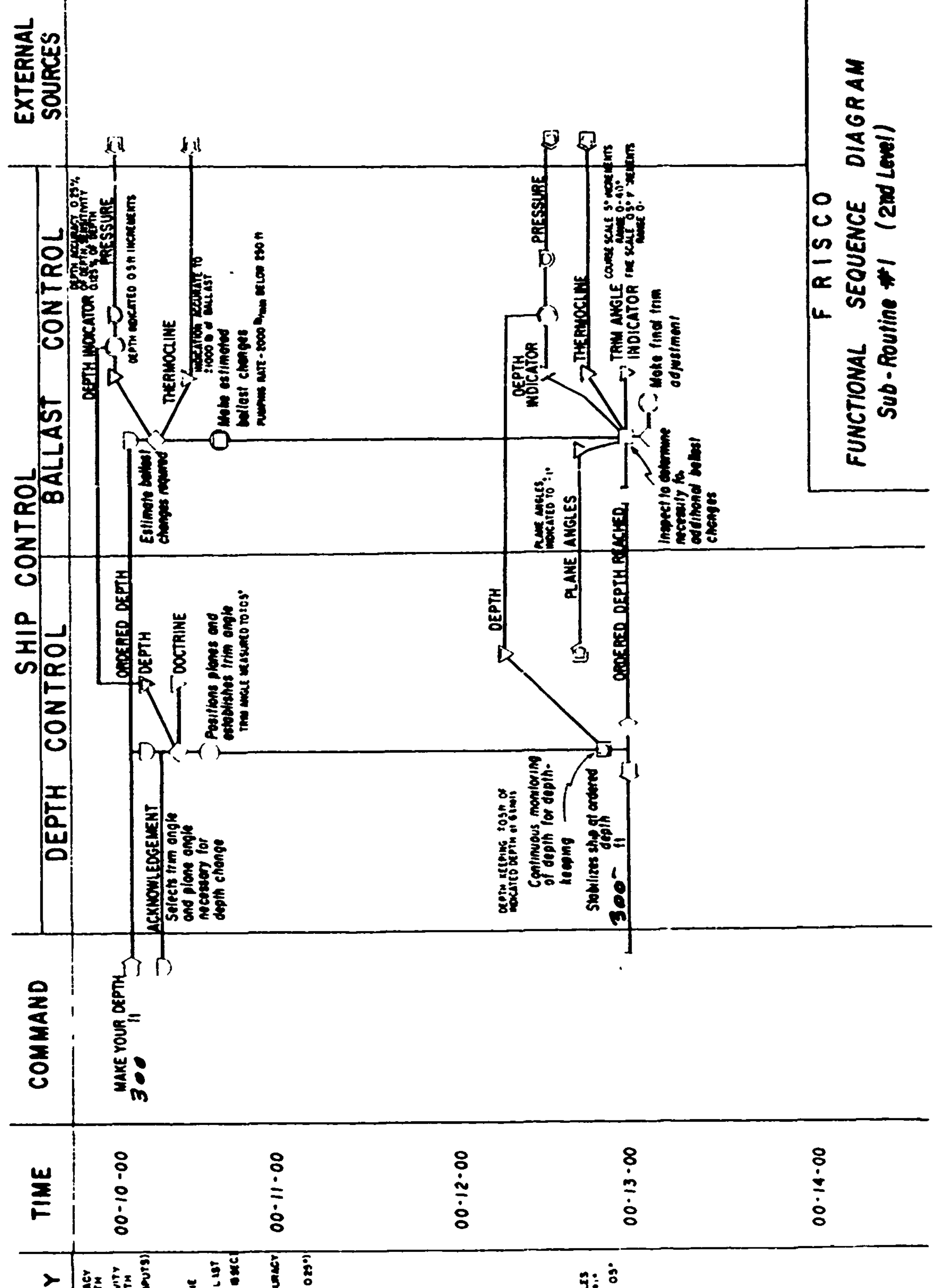

DATA QUALITY
TIME
COMMAND
SHIP CONTROL
DEPTH CONTROL
BALLAST CONTROL
EXTERNAL SOURCES
00-10-00
00-11-00
00-12-00
00-13-00
00-14-00
MAKE YOUR DEPTH 300 ft
ACKNOWLEDGEMENT
Selects trim angle and plane angle necessary for depth change
ORDERED DEPTH
DEPTH
DOCTRINE
Positions planes and establishes trim angle
Estimate ballast changes required
DEPTH INDICATOR
PRESSURE
THERMOCLINE
Make estimated ballast changes
Continuous monitoring of depth for depth-keeping
Stabilizes ship at ordered depth 300 ft
ORDERED DEPTH REACHED
PLANE ANGLES
DEPTH INDICATOR
TRIM ANGLE INDICATOR
Make final trim adjustment
Inspect to determine necessity for additional ballast changes
F R I S C O
FUNCTIONAL SEQUENCE DIAGRAM
Sub-Routine #1 (2nd Level)

FIGURE 8

system parameters are. A series of curves are derived on which cost-effectiveness studies are based to determine the accuracies required for the overall system. It may be possible to show that it is better to avoid a situation which requires extremely stringent accuracies rather than try to build the accuracy capability into the equipment. Thus, these data quality curves form the basis for a study on the trade-offs possible in the design of a ship.

Another tool, used in conjunction with the functional sequence diagrams, is the timing sequence diagram. An example of such a diagram is illustrated in Figure 9. The FSD does not show the amount of time that it takes to perform a given operation or whether certain operations must be performed continuously. The timing sequence diagram shows the typical elapsed time to perform a given function, thereby illustrating whether the timing requirements are stressing the system.

Once the functional data is obtained at the lowest level, it is possible to bring all the specialty areas together to observe the detailed information flow for a given operation as shown in Figure 10. It is at this point that accidental functional duplication will become apparent as two or more subsystems are seen to be performing the same function. Data quality mismatches will also become obvious if one subsystem requires data to a given degree of accuracy but it is being supplied with a different accuracy from another subsystem. It is possible that one subsystem may be found not to be providing data to another subsystem requiring it since this requirement was not previously known.

After this stage of design has been completed, all the n^{th} level FSD's are summed over all the different situations to end up with one functional system block diagram. The data for the construction of the block diagram

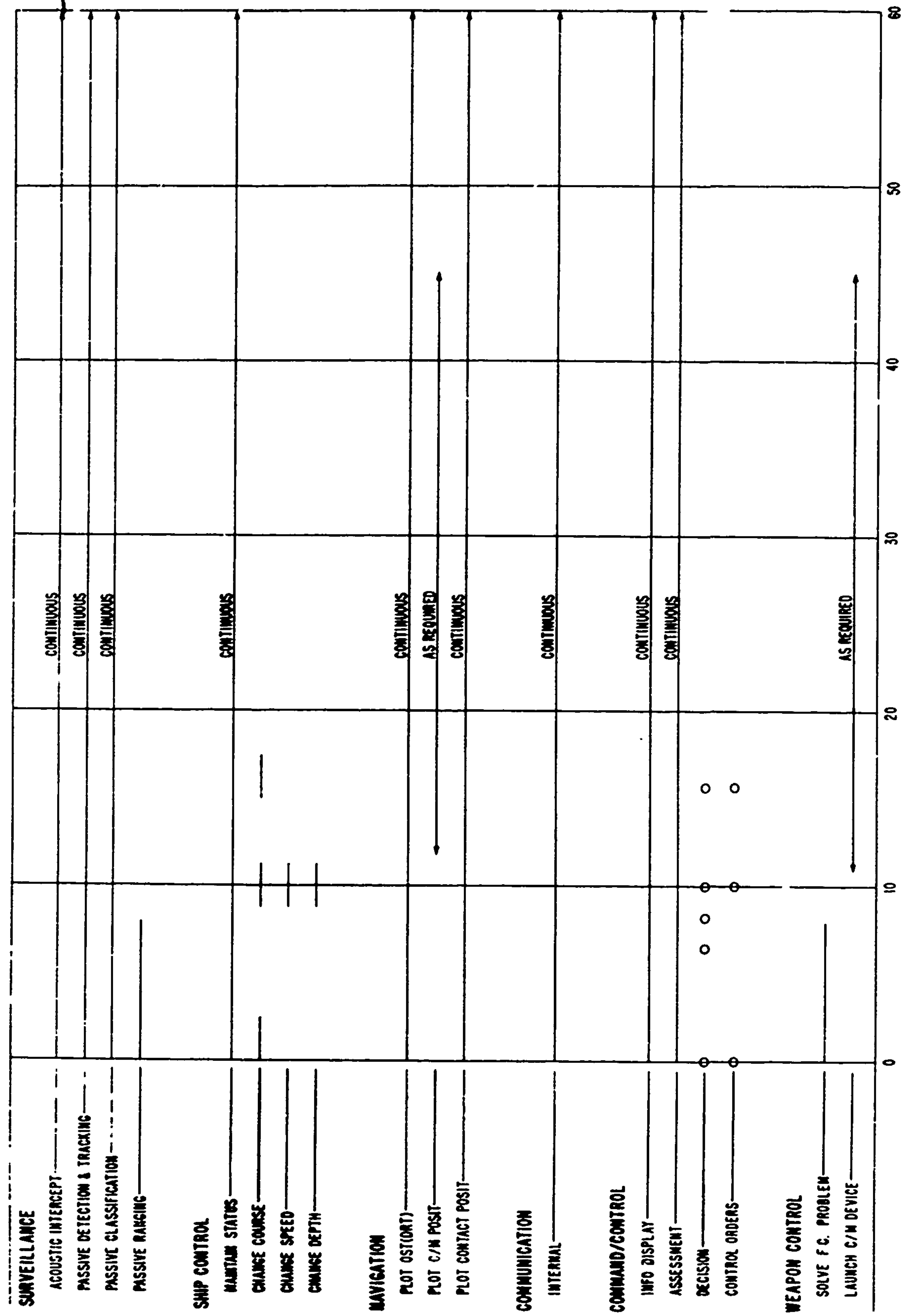

SURVEILLANCE
ACOUSTIC INTERCEPT
PASSIVE DETECTION & TRACKING
PASSIVE CLASSIFICATION
PASSIVE RANGING
SHIP CONTROL
MAINTAIN STATUS
CHANGE COURSE
CHANGE SPEED
CHANGE DEPTH
NAVIGATION
PLOT OST(OWN)
PLOT C/M POSIT
PLOT CONTACT POSIT
COMMUNICATION
INTERNAL
COMMAND/CONTROL
INFO DISPLAY
ASSESSMENT
DECISION
CONTROL ORDERS
WEAPON CONTROL
SOLVE F.C. PROBLEM
LAUNCH C/M DEVICE
CONTINUOUS
AS REQUIRED
0
10
20
30
40
50
60
TIME-MINUTES

FIGURE 9

FRISCO

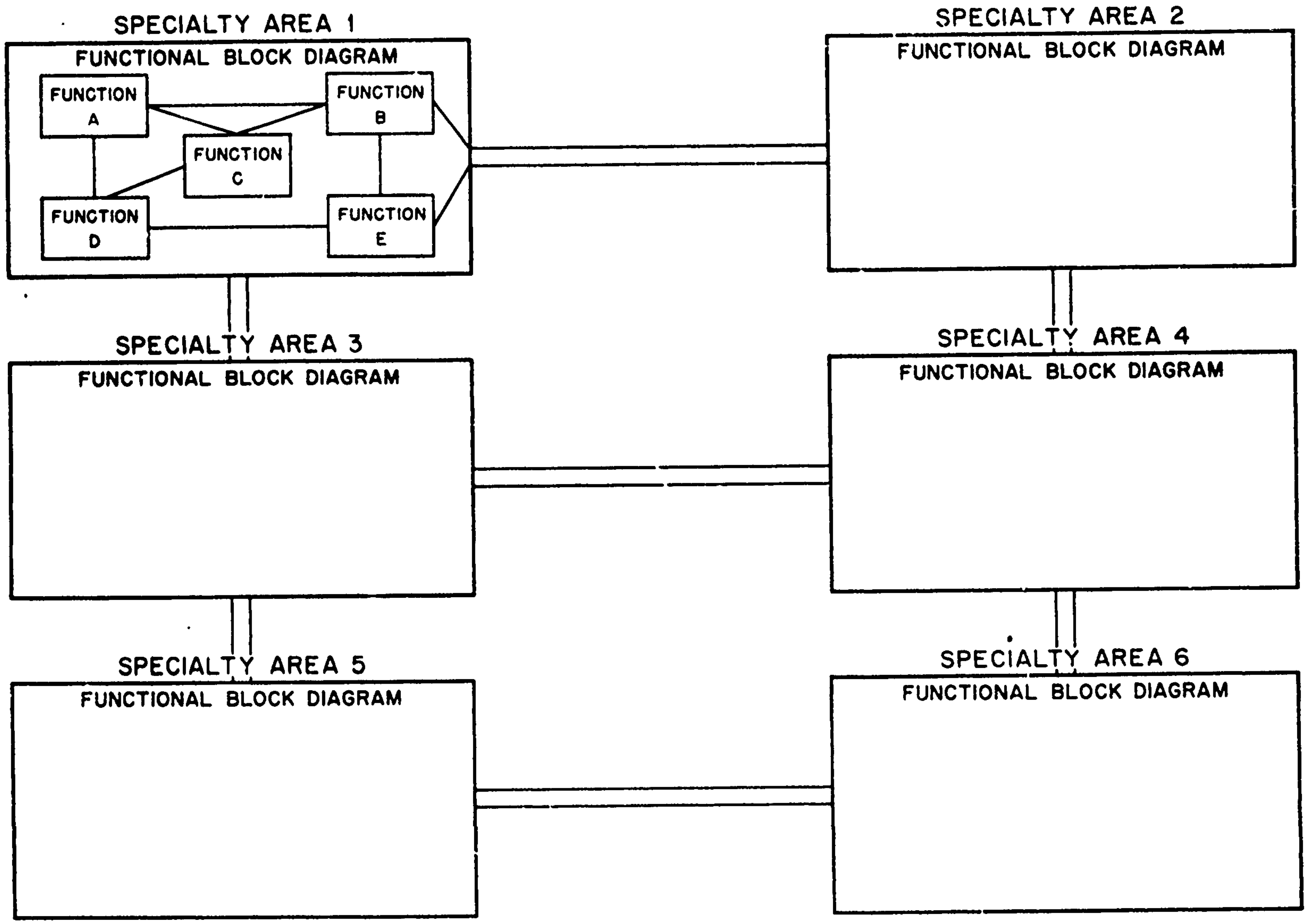


FIGURE 10

is determined from the FSD's. Now it is possible to isolate another, more subtile, duplication of functions which occurs where a mathematical process being performed in one subsystem is analogous to that done in another subsystem.

After the system block diagram is completed, a traffic flow analysis is performed to reveal how often the various functions are used together in different situations. Thus a count is obtained on the number of times function A is related to function B or function B to function C, etc. This analysis may show, for example, that certain functions within the ship control subsystem relate to functions in weapon control much more often than they do to other functions within ship control. Therefore, those functions should be regrouped with the weapon control subsystem. Thus, functions that are frequently used together can be grouped together to form optional subsystems. In this way, subsystems are determined on a functional information flow basis rather than on a historical, and possibly outdated, one.

Once the functional subsystems have been defined, the subsystem and system syntheses are performed. Various configurations of men and machines are postulated, trade-off and cost-effectiveness analyses performed, and the final optimized system determined. At this point, equipment and personnel are specifically named to perform all the required functions. Given this data, the operational sequence diagram (OSD), such as shown in Figure 11, may now be employed. With this tool which was originally developed by Dunlop Associates in 1959, the information flow is again traced but now the column headings represent "equipments" and "people" rather than "functions." Symbology is used to describe the manner in which information is transferred -- electrically,

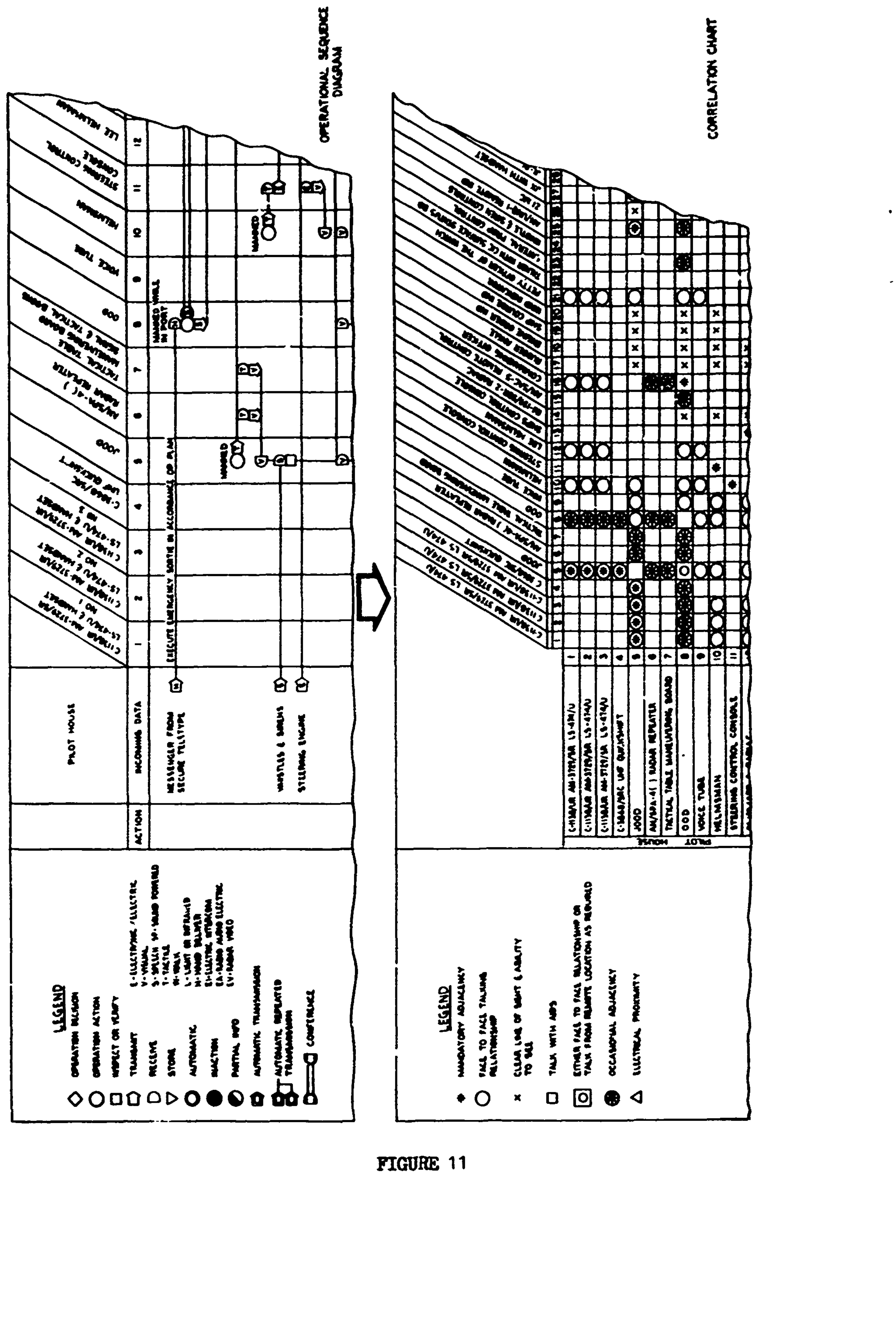


FIGURE 11

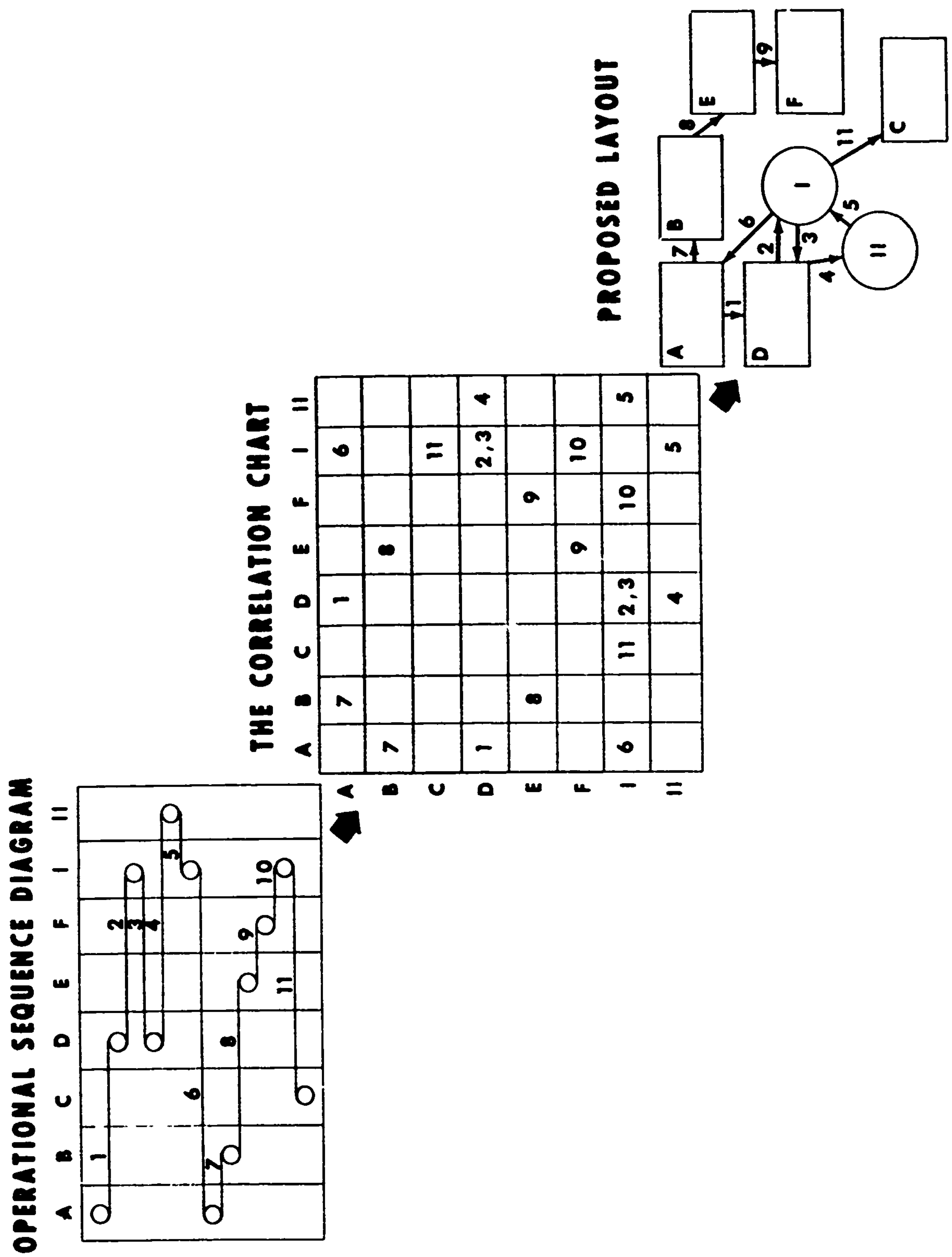
visually, audibly, tactually, etc. Any equipment mismatches, previously overlooked, will become apparent at this point. One can observe the column on the diagram corresponding to any person aboard the submarine to determine whether he is overloaded in performing a certain operation. Perhaps, another may be needed to share his duties, or if he is under-loaded he might share the duties of someone else who is overloaded to reduce manning requirements aboard the ship.

Upon completion of the OSD's, the next step is to use multiple correlation charting. This chart, which is believed to have been originated by the British, is used to determine the specific arrangement of men and equipment aboard the submarine. Vertical and horizontal chart headings are identical and represent the men and equipments studied in the operational sequence diagrams. Through use of this tool, it is possible to provide adjacencies (and relationships) as required.

Figure 12 shows the path by which an operational sequence diagram is used to form a correlation chart which in turn yields a layout with optimized information flow.

The sum of all the previously mentioned analytical techniques makes up the FRISCO system design procedure. It is important to note that none of these techniques automatically perform the engineering of the system. The same talented engineers are still required in the design process. However, the techniques provide, at the very least, a communications tool for people who are working towards the same goal but are geographically separated by large distances. They also provide a method by which interface problems can be isolated and resolved.

It is believed that these techniques should prove to be very useful in systems design. There is as yet no evidence of this in FRISCO since



	A	B	C	D	E	F	I	II
A		7		1			6	
B	7				8			
C							11	
D	1						2,3	4
E		8				9		
F					9		10	
I	6		11	2,3		10		5
II				4			5	

FIGURE 12

the FRISCO program is at the beginning of the series procedures. If the tools do prove to be useful, an enormous step forward will have been taken in the field of system analysis by providing industry with a set of analytical techniques in system design.

RELIABILITY AND MAINTAINABILITY CONSIDERATIONS IN SYSTEM DESIGN

Presented at

Northeastern States Navy Research and Development Clinic
Philadelphia, Pennsylvania

19 November 1964

by Paul J. Giordano
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Electronics Division
U.S. Naval Applied Science Laboratory
Brooklyn, New York 11251

RELIABILITY AND MAINTAINABILITY CONSIDERATIONS IN SYSTEMS DESIGN

The need for a systems engineering approach in the design of Naval Warfare Systems is becoming increasingly apparent. We in the Naval Material Support Establishment are being asked to make trade-offs of basic system effectiveness parameters like Performance, Reliability and Maintainability. These trade-offs are made with respect to budget, manpower, and physical constraints where cost includes operational as well as investment dollars and manpower considerations include skill level as well as numbers of technical people. (Slide 1)

The optimization problem is further complicated by the time parameter in that system development is an evolutionary process where the parameters to be considered and the data available to guide decisions will vary in detail and significance as a function of the particular point in the development cycle one may be at. Also, with respect to time as a parameter, the operational need for a system will impose a lead time constraint which in some cases could become the overriding constraint.

Finally, for trade-offs to be meaningful, all parameters must be related to specific measures of effectiveness. Detailed studies underway at the Naval Applied Science Laboratory for the *PACED program are aimed at the development of analytic techniques for guiding the program-manager in making these necessary trade-offs. It has been found that the major problem to be solved is that of defining the specific mission oriented or operational measures of effectiveness and relating these measures to parameters which the design

(*Program for Advanced Concepts in Electronic Design)

IMPROVE

Performance
Availability
Reliability

OPERATIONAL AVAILABILITY

System Effectiveness

With Efficient Utilization of Resources

Manpower
- Numbers
- Skills

Cost
- Development
- Investment
- OPERATION

Within Physical Constraints

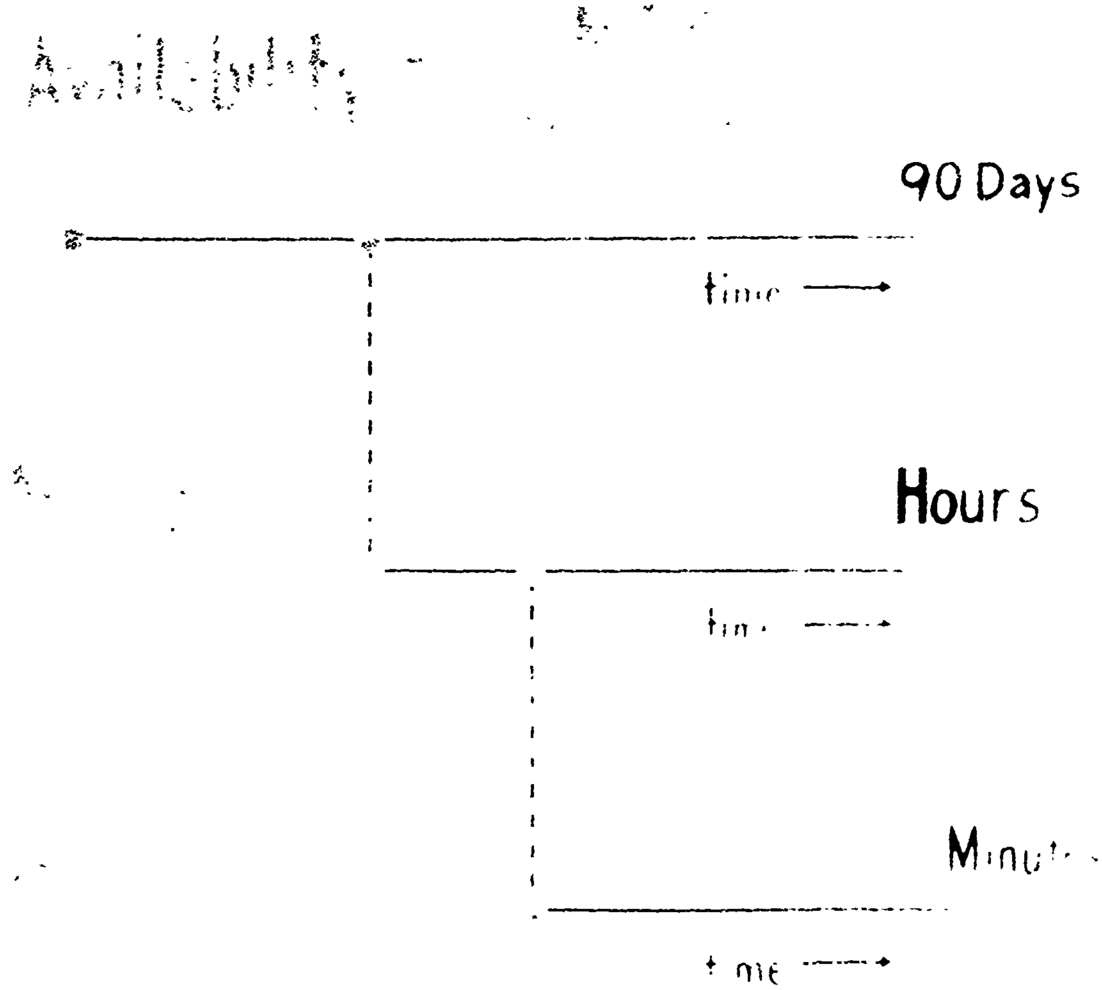
SPACE · WEIGHT · ENVIRONMENT

engineer can work to. This translation of effectiveness measures will help solve the communication problem which exists between the producers and the users of Warfare Systems.

Looking at one of the parameters of systems effectiveness, namely, operational reliability, one can readily see how failure to relate parameter values to mission tasks can lead to erroneous trade-offs. (Slide 2) The measure availability, for example, implies that repair rate and failure rate reductions can equally improve the probability of having a system operational at a point in time. However, if the mission requires sustained performance for a particular duration then the product of availability and reliability becomes the measure of success and the failure rate becomes the more critical parameter. Finally, if mission analysis shows that certain maximum maintenance time constraints are allowable without mission degradation, then repair rate again becomes critical.

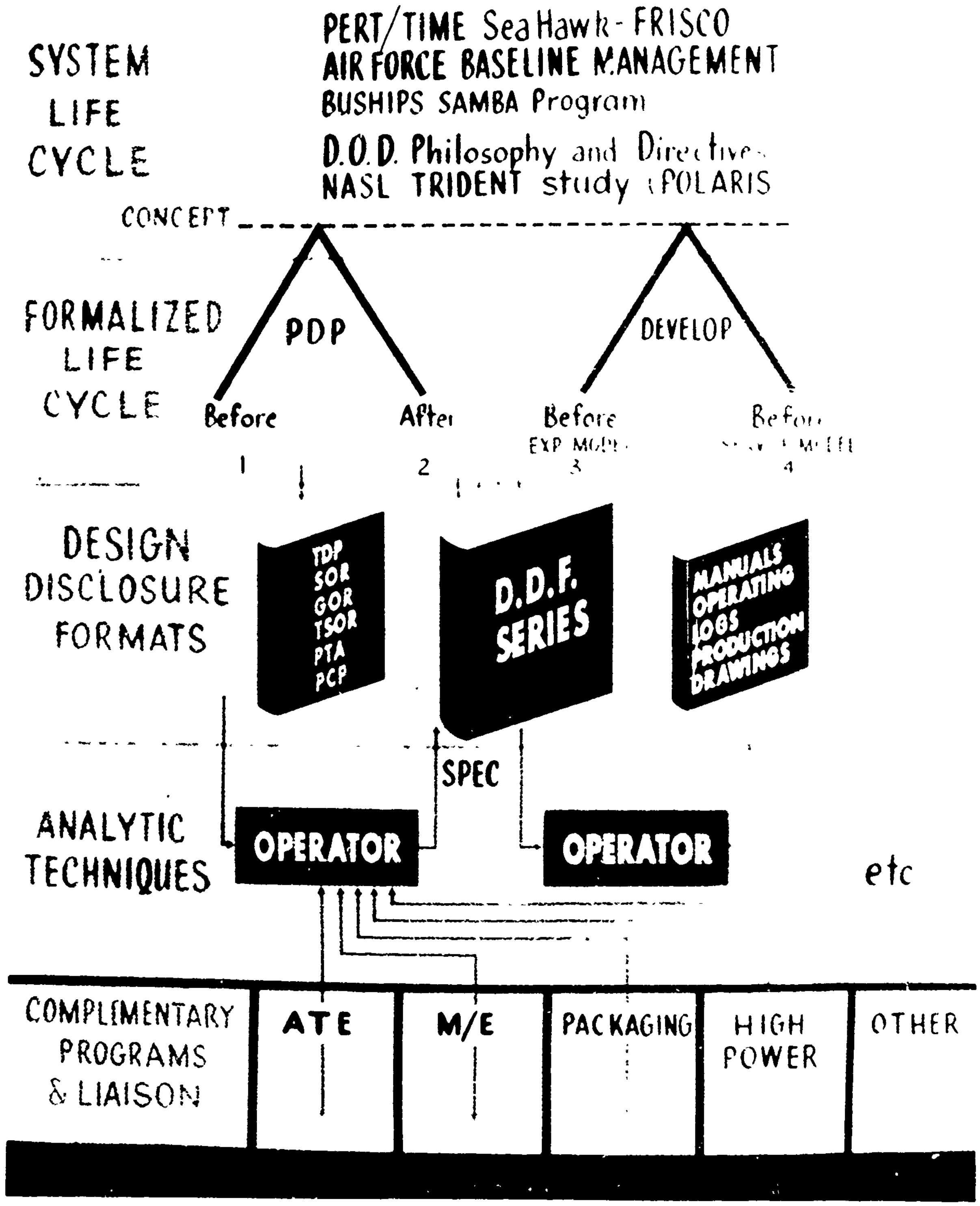
The PACED program is a broad program which is looking at all the facets of system effectiveness. (Slide 3) Briefly, we are looking at system development life cycles from concept to operational phases. Various studies in existance are attempting to uniquely define a formalized development cycle. PACED has identified four major points in this cycle occurring during the concept and development phases in order to study the time related problems of system development. Engineering studies are underway to develop Design Disclosure Formats for complete disclosure of the system at these points in order that a proper information source could be available to facilitate utilization of

OPERATIONAL RELIABILITY



Probability of Accomplishing a Specific Mission Task

OVERALL PROGRAM RELATIONSHIPS



analytic techniques for major trade-off decisions. Data accumulated through studies of automatic test concepts, microelectronics, packaging, and high power devices will be made available to program managers for introduction to new systems at the appropriate point in the development process.

The purpose of this paper is to describe those portions of the PACED program specifically oriented toward providing concepts and techniques which would enable the introduction of Reliability and Maintainability into system design.

The first important consideration, of course, is the development of requirements for reliability and maintainability. The problem here goes beyond merely stating goals for our system. Reliability and Maintainability, when specified, must be considered contractually in the same manner as any other system parameter. This implies that attitudes must be properly oriented, which further implies that reliability training must be actively pursued.

The second important consideration involved in successfully introducing Reliability and Maintainability to design lies in active participation during the development process. Today's systems have become so complex as to require much more than specifications and acceptance testing by the Military. We must become technical managers of our systems and through carefully planned design reviews we must actively participate during the evolutionary process of design.

To participate we need:

1. A store of data and knowledges to guide our decisions and
2. A method of communication.

The data we need must consist of information in the areas where possible solutions to the Reliability/Maintainability problem may be found. These solutions take many forms. (Slide 4) The degree and type of automatic testing, the mechanization techniques, the kind of redundancy, the use of de-rating, and the use of microelectronics are some of the possible solutions available to the program manager. If the designer is to take advantage of any proposed scheme he must have quantitative data which describes the approach in terms of his basic measures of effectiveness. For example, the impact of microelectronics and modular design must be known not only in terms of failure rates and ease of maintenance but also in terms of cost and effect on logistics. Alternate test concepts must be disclosed in terms of effect on space, people and budget as well as prime system repair times.

An example of how one could assist the design engineer through disclosure of state of the art information in a useful form is shown in the PACED efforts related to microelectronics and modular design (slide 5). In order to support the program manager in this area, current and planned packaging concepts are being described and documented in a Design Disclosure Workbook. Care is being given to detailing basic parameters so that alternate systems could be synthesized from this information. Specific knowledges gained by engineers who assisted in the design of these systems is also being documented through regular working meetings of a packaging committee set up by PACED with membership

POSSIBLE SOLUTIONS

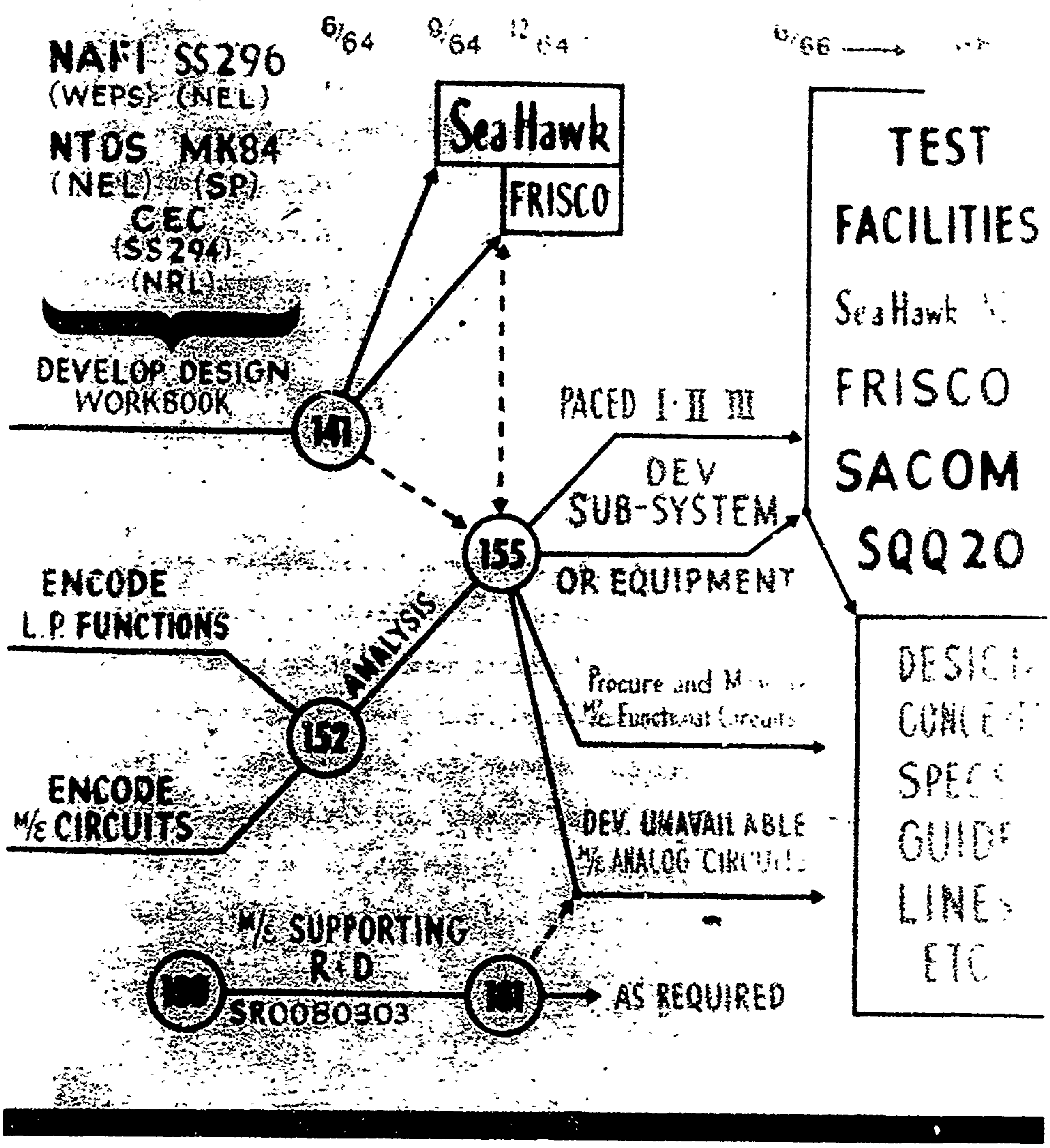
Maintainability Improvement

- Automated Testing
- Modular Construction

Reliability Improvement

- Redundancy
  - Fail Safe
  - Stand by
  - Usable
- De-Rating
  - Component De-rating
  - Environment Control
- Microelectronic
  - Thin Film
  - Solid Circuit
  - Hybrid

MICROELECTRONICS AND MODULAR DESIGN



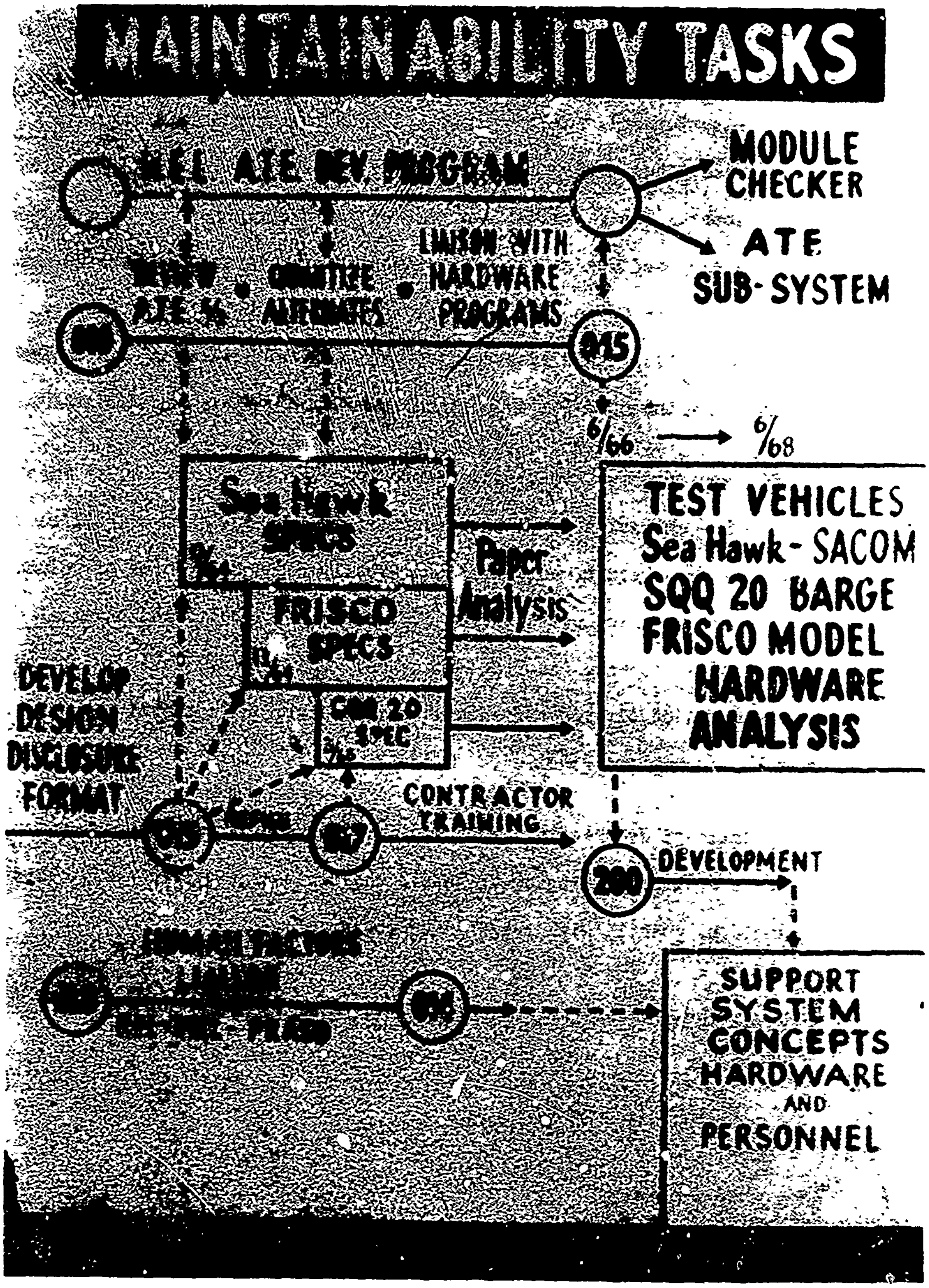
from Bureau of Ships, Bureau of Naval Weapons, Office of Naval Research and their Laboratories. This Workbook will be supplemented by a library of available circuit functions of modular designs, available microelectronic circuits, and functional makeup of major Naval Systems. Correlation programs have been developed so that data processing equipment could be used for correlating proposed functional boundaries for new designs against available designs and available microelectronic circuits. The microelectronic functions encoded include data from National Aeronautics and Space Administration, Air Force and Army programs. Although the long range objectives of this portion of the PACED program are to develop specific mechanization techniques, it is important to note that the early availability of data, via the Design Disclosure Workbook for packaging parameters, and, the Data Library for circuit functions, will enable Naval system designers to introduce available concepts to current designs. In order to be of general use to Laboratories and contractors the library will be maintained by the University of Pennsylvania. A handbook on its applicability and use will be published early in 1965.

The second requirement mentioned for allowing active effective participation in the development process is the need for a means of communication between the designers of our systems and the technical managers of our programs. This need became very apparent to the Laboratory during the planning stages of a total support system for advanced ASW surface ships and submarines. We learned that support systems and support system concepts could not be applied without sufficient knowledge of the prime system. In addition, in order to avoid costly retrofits the information must be available during the early design

phases. The maintainability tasks developed by the PACED program recognized this need and emphasized in support system development the requirement for documentation which we call Design Disclosure Format (DDF). The philosophy adopted is straightforward, namely: Once a requirement for maintainability has been specified, then the responsibility for achieving this is clearly with the prime developer. The technical managers of the program must be able to then review the proposed design for maintainability and introduce specific hardware concepts where needed to effect necessary improvements. The contractor documentation must allow rapid assessment of the maintainability of his design as well as indicate the need for support equipment and support personnel. (Slide 6)

The DDF requirements have been generated to present only necessary information. Through elimination of unwanted data it is expected that overall contractor documentation requirements will be actually reduced in terms of volume and cost. The DDF requires presentation of functional circuits and physical boundaries to allow hardware interface analyses. Operational, test, and power circuits are independently identified and charts showing operational sequences and circuit dependency are required. (Slide 7)

The operational sequence diagrams are currently being developed by the Bureau of Ships Work Study Program to enable their use as a design tool. This work is being done jointly with the FRISCO program.


MAINTAINABILITY TASKS
ATE DEV PROGRAM
MODULE CHECKER
ATE SUB-SYSTEM
LIAISON WITH HARDWARE PROGRAMS
015
6/66
6/68
Sea Hawk SPECS
FRISCO SPECS
Paper Analysis
TEST VEHICLES
Sea Hawk - SACOM
SQQ 20 BARGE
FRISCO MODEL
HARDWARE
ANALYSIS
DEVELOP DESIGN DISCLOSURE FORMAT
CONTRACTOR TRAINING
200
DEVELOPMENT
SUPPORT SYSTEM CONCEPTS
HARDWARE
AND
PERSONNEL

DESIGN DISCLOSURE FORMAT

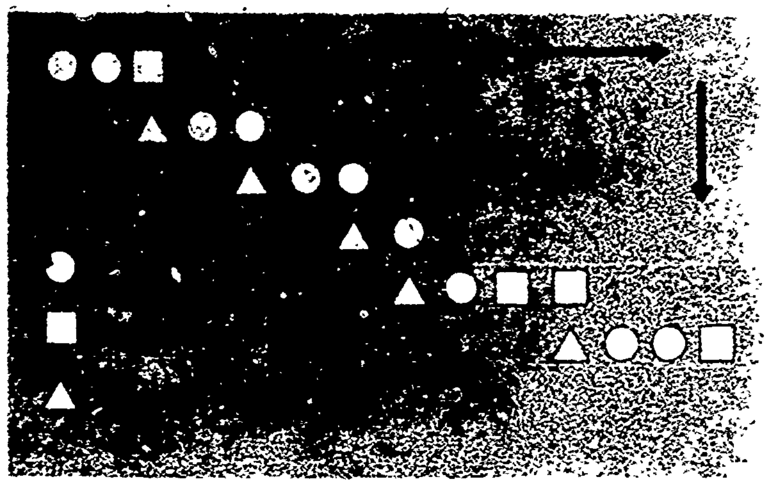
- Clear Presentation of functional Circuits
- Clear Presentation of physical configuration
- Clear Presentation of:
  - Information flow
  - Test and Exercise Circuits
  - Power and Control Circuits
- Circuit and I[illegible] Dependency charts
- Operational Sequence charts

The dependency chart being developed by the PACED program provides the tool for maintainability analysis during design. This information will allow system analysis of the maintenance tasks for an entire shipboard suit using a uniform format and will result in better integration of the maintenance function (utilization of inherent sensors, computer capacity, etc.). In particular, the availability of a Circuit and Indicator Dependency Chart early in the acquisition cycle before designs become frozen would have a major impact on improvement of the ultimate design of equipment. Design adequacy with respect to test point selection and the ease with which a fault can be bracketed to simplify potential man-machine interfaces will be enhanced, so that problems can be quickly discerned and effective design modifications made. (Slide 8)

A preliminary report on this technique has been issued and a detailed technical report describing DDF content and intended application is currently being reviewed for release in January 1965. Coordination has been started with the Bureau of Naval Personnel and their field activities and program managers within the Bureau of Naval Weapons (A-NEW Program), the Bureau of Ships (SEAHAWK, FRISCO, SOUTHERN CROSS Programs) and Defense Communications Agency (DCA)(COMSAT Program) have been technically oriented on DDF use for support system development.

In summary, PACED is specifically addressing itself to <u>how</u> one introduces Reliability and Maintainability to system design. The solution lies in taking the simple statement "apply state of the art through effective liaison" and making it work. This involves the development of techniques described herein

DEPENDENCY CHART



Implications

- Allows Equipment Analysis by Contractor & Navy
- Allows System Analysis by Contractor & Navy
- Shows Logical Troubleshooting Sequence
- Compatable with Computer Logic for Automated Surveillance if Required
- Minimizes Transfer of Training Problem

for documenting information and allowing effective communication. These techniques have been presented to Industry through EIA conferences and private meetings. The implementation of these techniques will be validated on selected subsystems. It is hoped that through application over time the techniques will be improved and ultimately contribute to the solution of current problems in the application of Reliability and Maintainability to system design.

ENGINEERING INTEGRATION IN SYSTEM DESIGN

PRESENTED AT THE

NORTHEASTERN STATES

NAVY RESEARCH AND DEVELOPMENT CLINIC

PHILADELPHIA, PENNSYLVANIA

19 NOVEMBER 1964

William D. Rohe, Jr.
Office of Naval Material
Department of the Navy

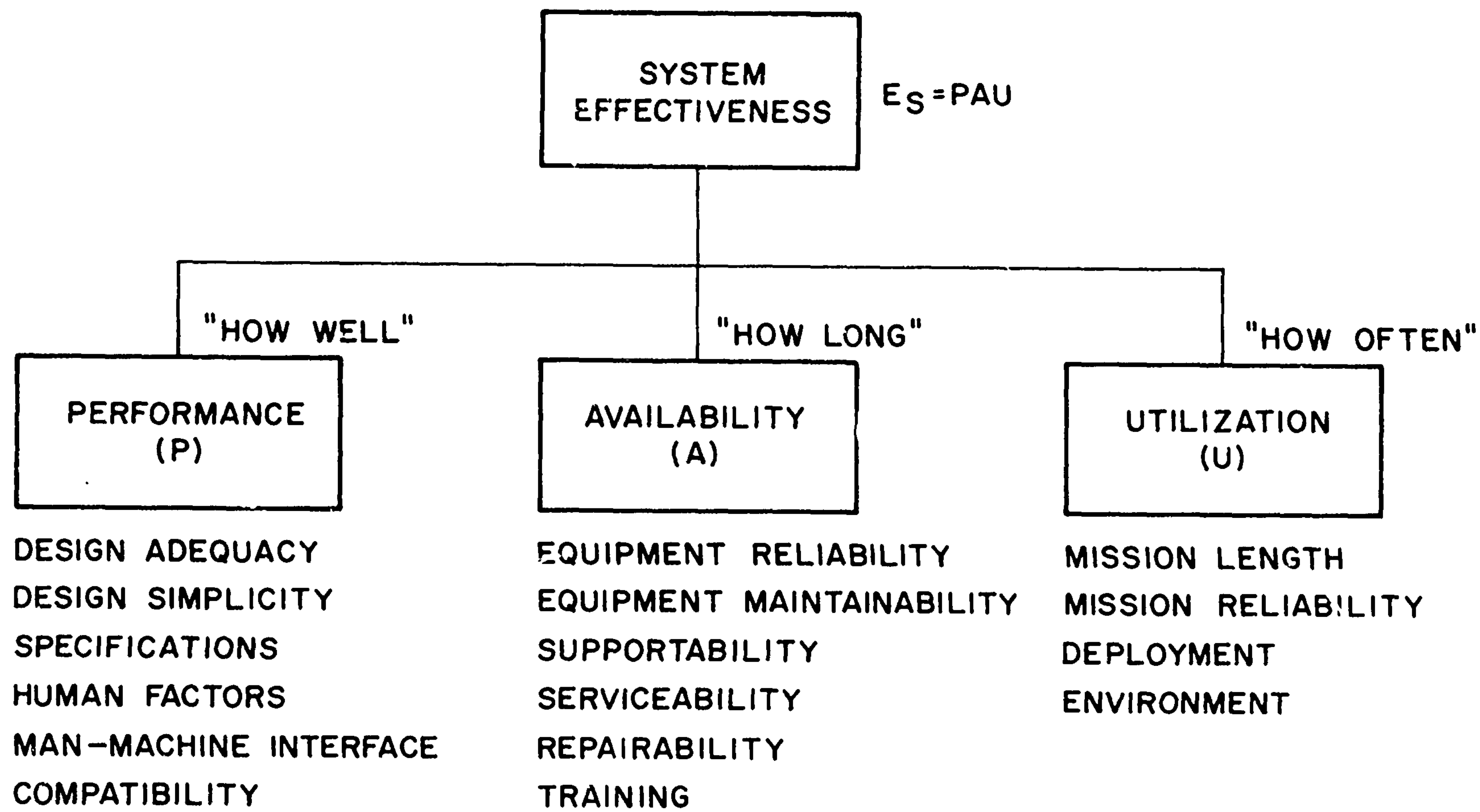
ENGINEERING INTEGRATION IN SYSTEM DESIGN

Introduction: You have heard previous discussions this afternoon concerning some facets of System Effectiveness, namely reliability and maintainability. Also discussed was the use of analytical techniques in determining the optimum system design to insure mission success. Here, the threat is analyzed and then various system configurations are evaluated through the use of threat and performance models. To bring the concept of System Effectiveness more into focus, I would like to summarize what I consider the pertinent elements of System Effectiveness.

(Slide #1 "Elements of System Effectiveness")

Elements of System Effectiveness: Simply stated System Effectiveness is defined as "the probability that the system (or material) will operate successfully when required under specific conditions." I am using the term system in the gross sense. The primary contributors to Effectiveness are PERFORMANCE, AVAILABILITY and UTILIZATION. PERFORMANCE indicates "How Well" the system operates. AVAILABILITY indicates "How Long" the system can function under certain conditions. UTILIZATION indicates "How Often" the system will be used. Other supporting factors associated with the primary elements include such items as design adequacy, man-machine interfaces, equipment reliability, serviceability, and environment. Of the three primary elements of System Effectiveness, the PERFORMANCE factor is the one that I would like to emphasize today.

Performance Through Design: In order to achieve the goal of PERFORMANCE, one must first consider system design, since design is the conjugate of PERFORMANCE. In addition to considering the design of the device or



SYSTEM EFFECTIVENESS
$E_S = PAU$
"HOW WELL"
PERFORMANCE (P)
DESIGN ADEQUACY
DESIGN SIMPLICITY
SPECIFICATIONS
HUMAN FACTORS
MAN-MACHINE INTERFACE
COMPATIBILITY
"HOW LONG"
AVAILABILITY (A)
EQUIPMENT RELIABILITY
EQUIPMENT MAINTAINABILITY
SUPPORTABILITY
SERVICEABILITY
REPAIRABILITY
TRAINING
"HOW OFTEN"
UTILIZATION (U)
MISSION LENGTH
MISSION RELIABILITY
DEPLOYMENT
ENVIRONMENT

SLIDE 1

subsystem under development, the parameters of associated peripheral equipment or subsystems must be analyzed. I am using the term subsystem to emphasize that any system is a part of a bigger system. A systematic engineering approach is required to insure complete interface compatibility, between major equipments. This engineering approach is called Engineering Integration. The key to this design appears to be through a System Effectiveness analysis of the total systems of which new developments would comprise a part. This analysis can help to focus attention on interface requirements in terms of performance and compatibility. For example, starting with the operational requirement of a weapons system, one can analyze the operational requirements of associated subsystems to determine such factors as overlapping requirements, redundancy, deficiencies, mutual support, incompatibility and the like. Additional questions such as the following might be asked. In terms of UTILIZATION, has subsystem A been designed for the same mission length as subsystem B (which is complementary and/or interdependent) for carrying out a specific mission? Are the same shipboard subsystems being designed for the same environment? Will complementary subsystems possess similar availability or operational readiness factors? Does subsystem A have a material reliability of 50% while System B, which is dependent on subsystem A, have a reliability of 95% and the overall mission reliability required is 90%? Further, in regards to PERFORMANCE, are connecting subsystems compatible or is subsystem A providing a digital output while existing subsystem B was designed previously to accept only an analog input?

Are man-machine interfaces being considered initially in the design or may operation of the equipments being developed result in undo strain and operator fatigue which will result in decreased Effectiveness?

As you see from the foregoing all aspects of System Effectiveness can and must be considered. PERFORMANCE must compete with AVAILABILITY and UTILIZATION and vice versa, but with each given its due weight. The Navy can no longer emphasize one segment of effectiveness at the expense of the other without regard to their relative contribution to mission completion.

<u>Design Approach</u>: Today I would like to briefly suggest some methods of approach to insure: (1) engineering integration of subsystems making up a whole system; and (2) compatible mating of the subsystem with the engineering interfaces connecting it to other mutually dependent subsystems. These techniques could be equally applied to the AVAILABILITY and UTILIZATION aspects. The ideal method to approach the problem would be to consider the complete system (Slide #2). Here, all aspects of design can be treated simultaneously. Unfortunately, since major portions of the system already exist the new subsystem must be injected in a piecemeal fashion. Nevertheless to minimize redesign and patching, a time-sequenced approach can be utilized (Slide #3). . system design is considered, however, but the implementation is time-phased as resources permit. As future system changes evolve due to changing needs, they can be assessed prior to their introduction in the system performance model. A critical examination of the change prior to implementation can insure minimum physical and functional disruption, provide smooth

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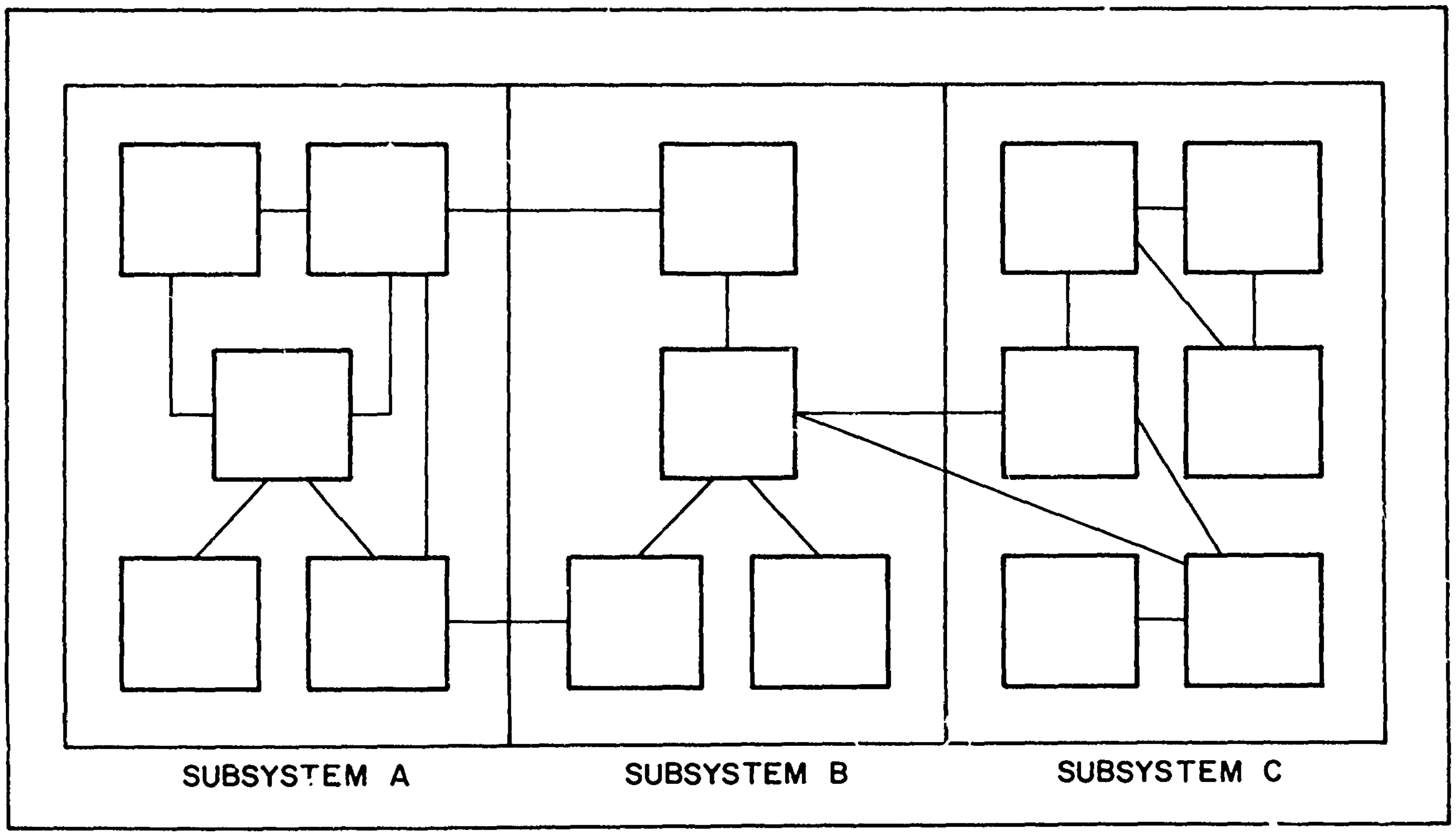
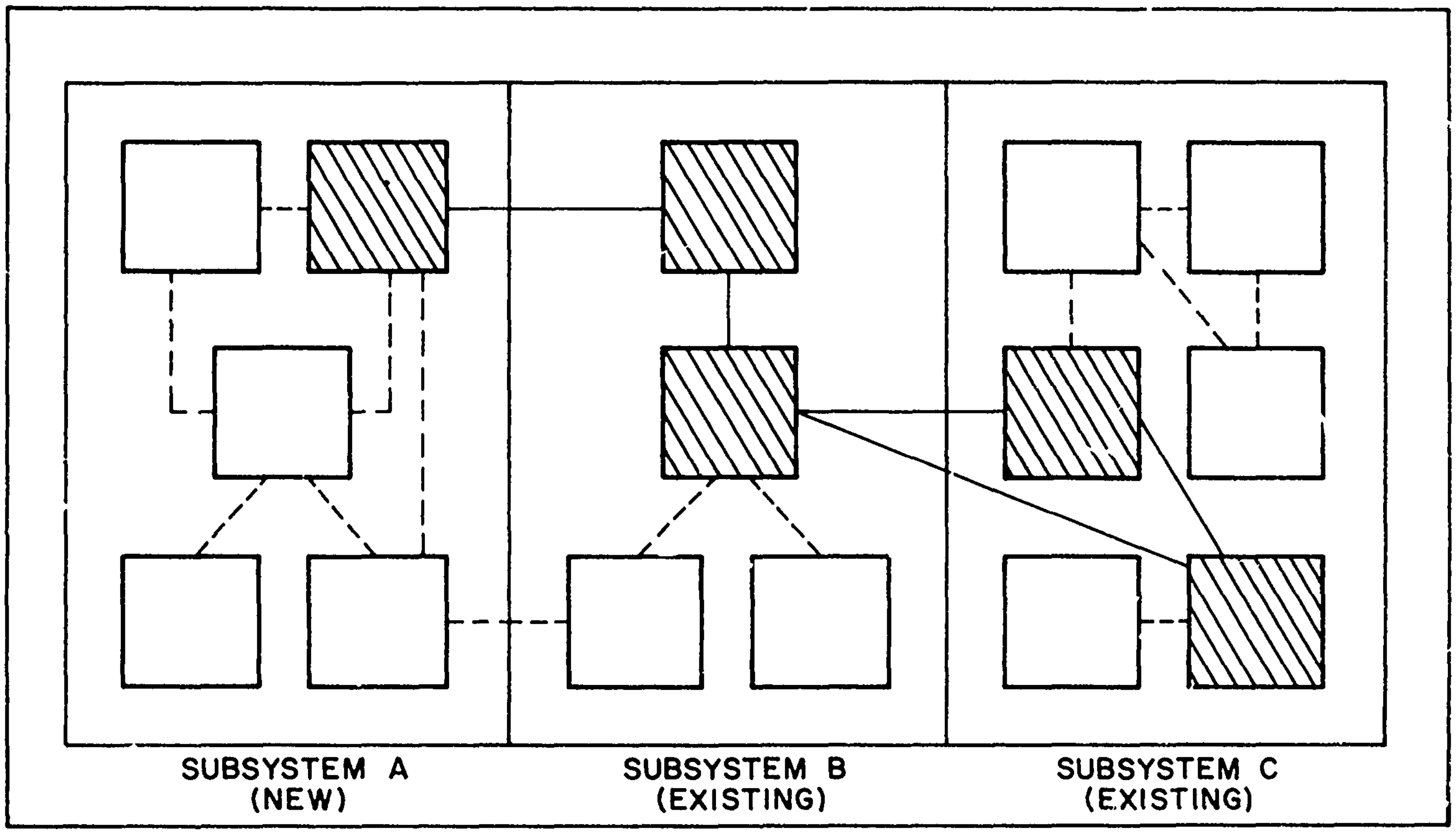
TOTAL SYSTEM DESIGN



SLIDE 2

TIME PHASED SYSTEM DESIGN



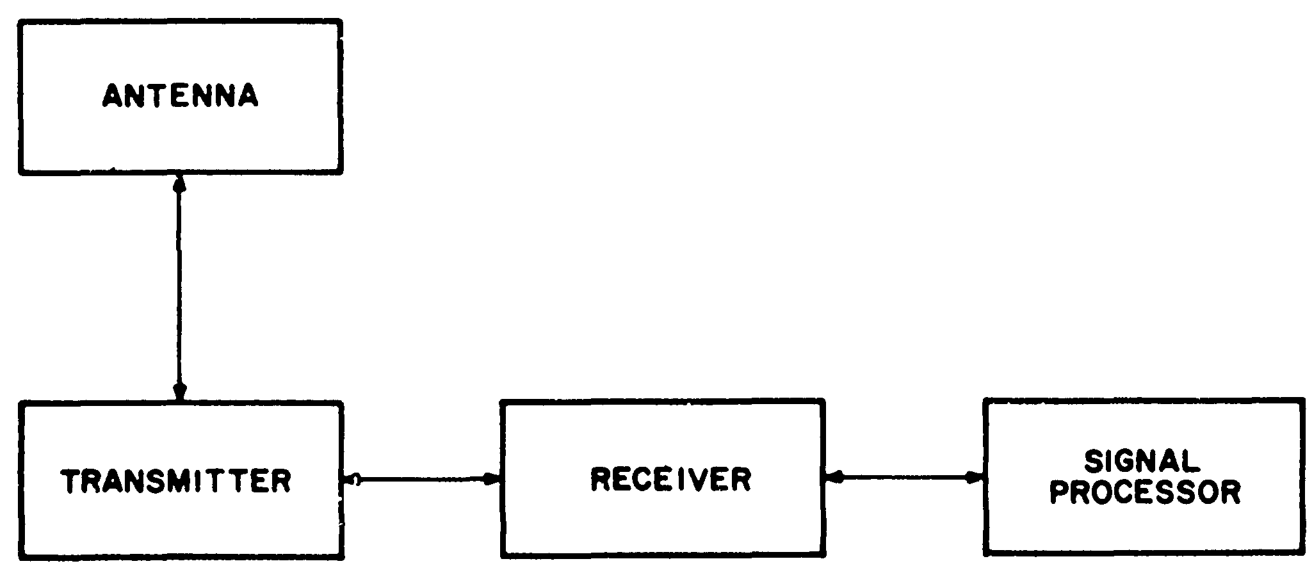
SLIDE 3

integration and minimize premature commitment of marginal changes.

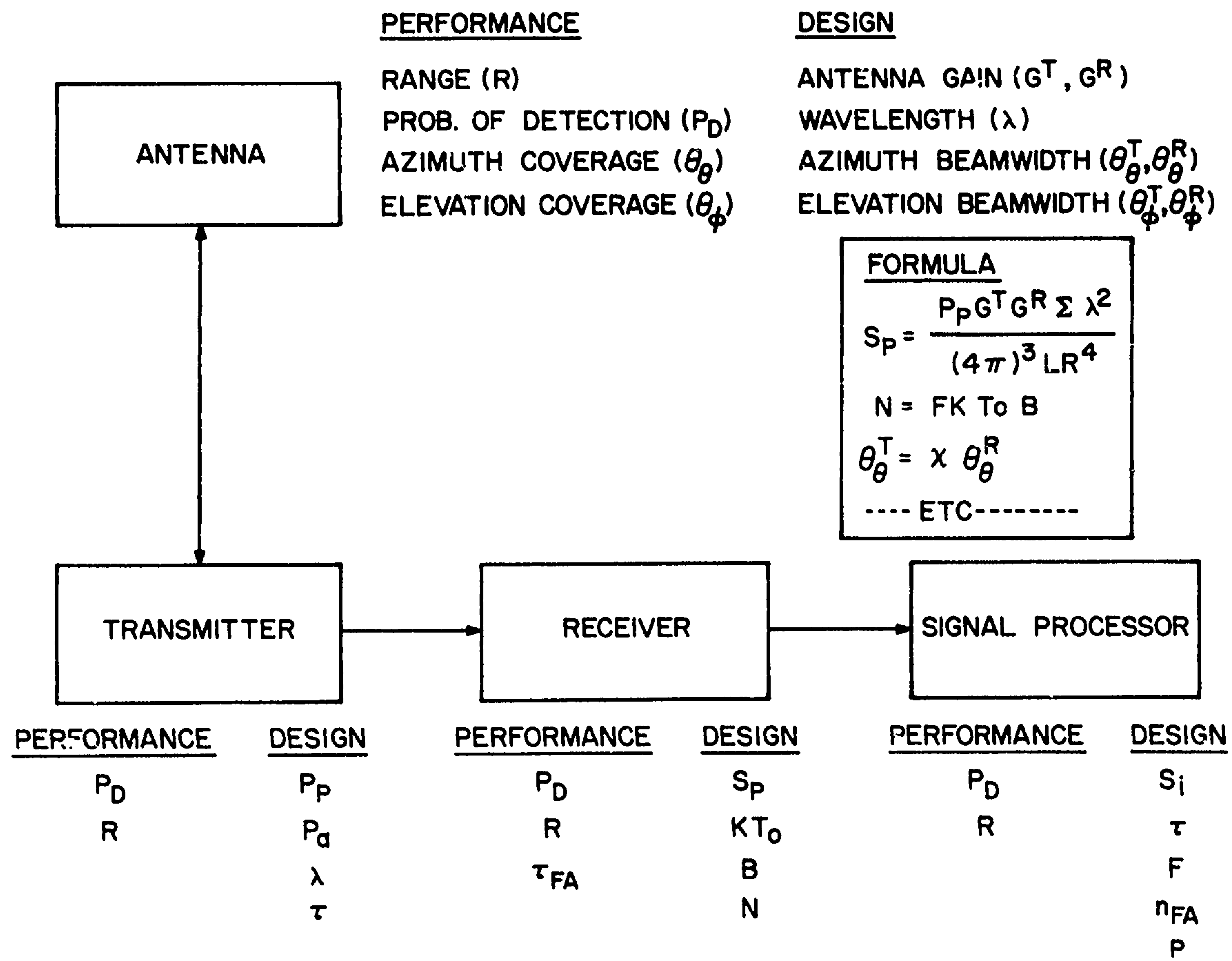
Functional Block Diagram: The ability of a system to accomplish its designated functions is described as PERFORMANCE and can be measured by the assessment of performance models. The subsystem performance requirements must first be translated into system design requirements and from there into design specifications. Generally an analysis of the functions of a system leads to the development of a system functional block diagram. For the first cut, only the major functions are considered, (Slide #4). The major blocks are in turn further broken up in successive steps as required to identify signal flow, transfer functions and tolerances.

The performance factors should be listed by each block along with the design parameters and applicable mathematical relationships, (Slide #5). Once the subsystem under development has been carefully analyzed, the next step is to go through a similar analysis with connecting subsystems via the interfaces. Here again performance requirements must be analyzed to insure that this new development will enhance overall performance and will not restrict it. Let us take the example of a surveillance radar system. One area to be analyzed is the capability of the radar to detect and identify the target in sufficient time at a high enough data rate so that: (1) the weapon designation equipment can assess the target threat and assign it to a missile system; and (2) allow the missile system sufficient time to react. Once it has been determined that the performance factors will improve overall system performance, then the physical and functional interfaces must be made compatible with

TYPICAL RADAR SYSTEM



SLIDE 4



PERFORMANCE
RANGE (R)
PROB. OF DETECTION (P_D)
AZIMUTH COVERAGE (θ_θ)
ELEVATION COVERAGE (θ_ϕ)
DESIGN
ANTENNA GAIN (G^T, G^R)
WAVELENGTH (λ)
AZIMUTH BEAMWIDTH ($\theta_\theta^T, \theta_\theta^R$)
ELEVATION BEAMWIDTH ($\theta_\phi^T, \theta_\phi^R$)
FORMULA
$S_P = \frac{P_P G^T G^R \Sigma \lambda^2}{(4\pi)^3 L R^4}$
$N = FK T_o B$
$\theta_\theta^T = X \theta_\theta^R$
---- ETC--------
ANTENNA
TRANSMITTER
RECEIVER
SIGNAL PROCESSOR
PERFORMANCE
P_D
R
DESIGN
P_P
P_a
λ
τ
PERFORMANCE
P_D
R
τ_{FA}
DESIGN
S_P
KT_o
B
N
PERFORMANCE
P_D
R
DESIGN
S_i
τ
F
n_{FA}
P

SLIDE 5

each other. The process of using functional block diagrams is repeated.

Summarization Diagrams

While the mathematical relationships among the variables can be identified by using system block diagrams, other interface considerations such as reliability, environmental specifications and man-machine relations, must be summarized. This may be done in form of PERT type network diagrams, matrices, or sequential diagrams.

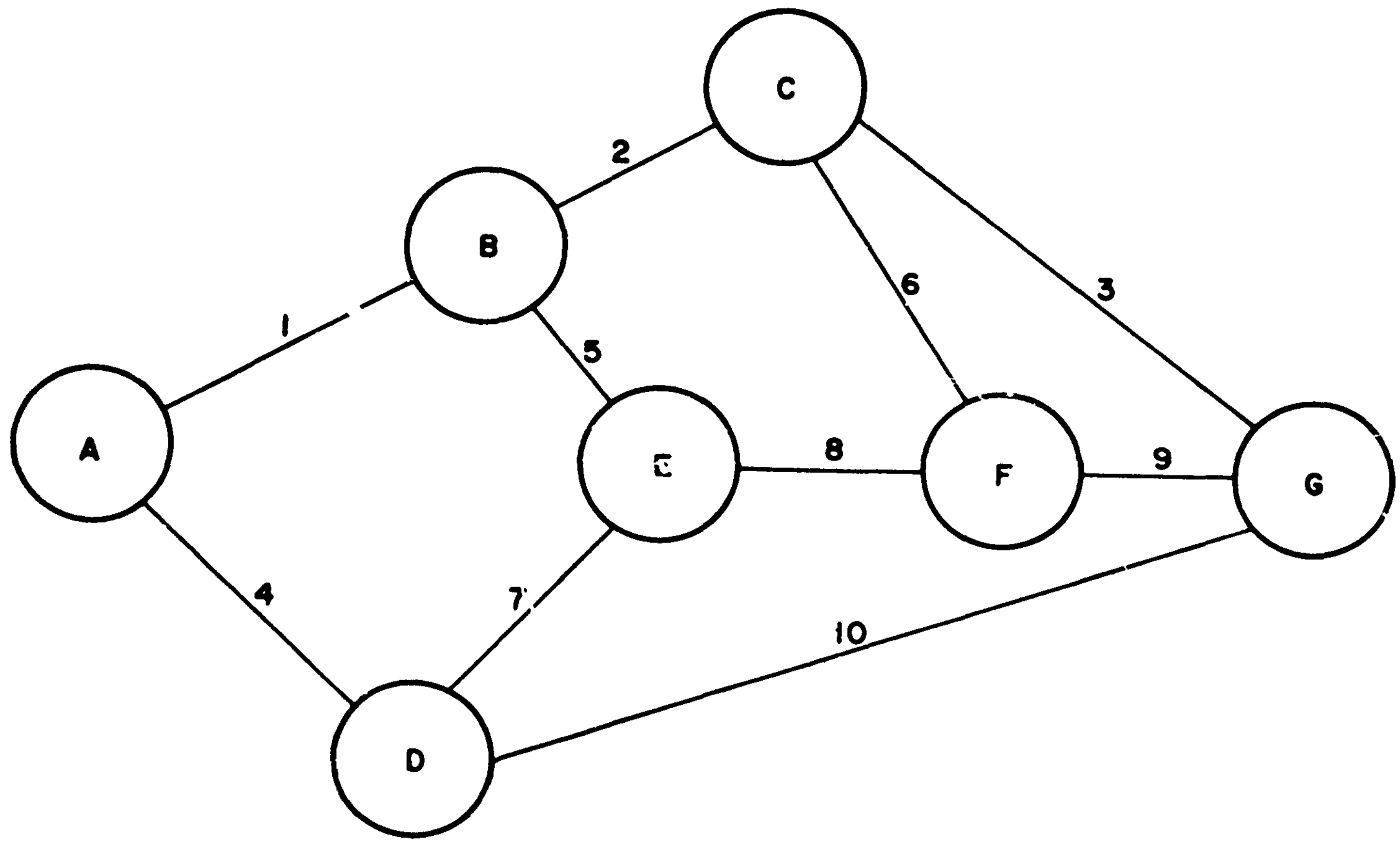
In the network diagrams (Slide #6) the events A, B, C, etc., represent variables at various subsystem levels. The activities denoted by 1, 2, 3, 4, etc., represent the functional relationships which exists between two variables.

The same type of information can be expressed in a matrix form (Slide #7). Using the same coding as the network diagram, the data is presented in a form which is suitable for programming into a computer. The network lends itself more easily to visually identifying relationships while the matrix is more suitable for storage and retrieval.

In the sequential diagram (Slide #8) relationships based on factors such as processes, information sources, decision and outcomes can be laid out in step fashion. This is an operational analysis type of approach which pictorially displays information-decision-action-flow sequences which a component or subsystem must undergo to complete its mission. This type diagram is now commonly used in man-machine interface analysis.

Other methods of summarizing both subsystem and system PERFORMANCE - DESIGN information include matrices showing PERFORMANCE vs DESIGN,

NETWORK DIAGRAM

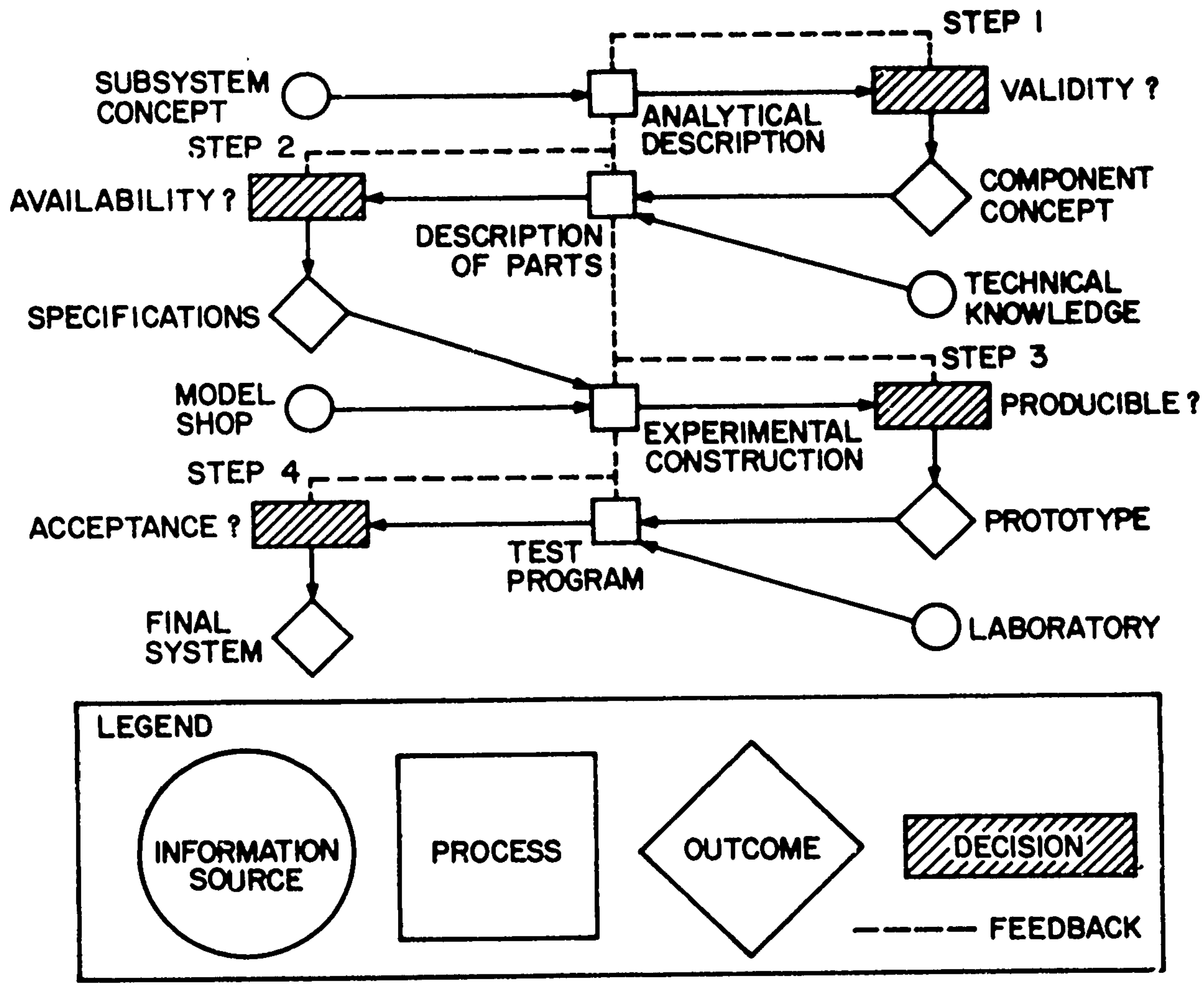


SLIDE 6

MATRIX DIAGRAM

	A	B	C	D	E	F	G
A							
B	1						
C		2					
D	4						
E		5		7			
F			6		8		
G			3	10		9	

SEQUENTIAL DIAGRAM



SLIDE 8

(Slide #9), PERFORMANCE vs PERFORMANCE, and DESIGN vs DESIGN, charts.

Design Interface Specifications

Since subsystem developments are not always under the management of the same agency, it is necessary to formally transmit design criteria from one agency to another. This can be done by using Design Interface Specifications (Slide #10). It is essential that this be done as soon as possible in the development in order to allow the receiving agency sufficient time to respond. It should be noted that there are always funding implications that must be reconciled. Interface engineering can be an expensive proposition and should not be overlooked. The slide shows some of the criteria that should be included in the interface specification.

Summary

My intent today has been to give you some feel of the magnitude of engineering integration. The developer of a subsystem can no longer live in a vacuum. He must be jointly responsible for interface design. Additionally, the Navy must apply total system engineering and not piecemeal engineering of individual subsystems.

PERFORMANCE VS DESIGN MATRIX

PERFORMANCE

DESIGN	R	P_D	θ_θ	θ_ϕ	τ_{FA}	G_R
P_P		✓				
P_a	✓					
KT_o		✓				
G^T		✓				
G^R		✓				

SLIDE 9

SAMPLE FORMAT

DESIGN INTERFACE SPECIFICATION		
AGENCY ______ PROJECT NO. ______ SUBSYSTEM ______	INTERFACE BETWEEN ______ AND ______	DATE ______ REFERENCES:

ELECTRICAL SIGNAL TYPE:	PROJECT STATUS:
ACCURACY:	DATE REQUIRED – R & D:
TOLERANCE:	DATE REQUIRED – PRODUCTION:
ENVIRONMENT:	FUNDING SUPPORT:
PHYSICAL INTERFACE:	OTHER:

SLIDE 10

PLANNING INTEGRATION IN SYSTEM DESIGN

PRESENTED AT THE

NORTHEASTERN STATES

NAVY RESEARCH AND DEVELOPMENT CLINIC

PHILADELPHIA, PENNSYLVANIA

19 NOVEMBER 1964

LCDR Gordon H. Jayne
Office of Naval Material
Department of the Navy

A little less than two years ago I participated in the briefing of a Fleet Commander on the status of the development and testing programs of various weapons and support systems. At the conclusion of the briefing, Admiral H. P. Smith, Commander-in-Chief of the Atlantic Fleet, made a few closing remarks which I think bear repeating.

The gist of the Admirals' remarks was as follows:

My ships are burdened with so-called sophisticated equipment and systems which have wonderful "press clippings" concerning their performance. But unfortunately, they won't work when we need them. These complex systems are generally unreliable and very difficult to maintain. When they work their performance is usually quite good. However, I would gladly sacrifice some performance for the sake of reliability and maintainability. My ships need equipment and systems that work when and where they are needed to work. They don't need any more junk installed in them.

Perhaps out of sheer frustration Admiral Smith may have overstated the situation. Nevertheless, there is more than a little substance to his comments. The situation the Admiral describes exists in varying degrees in the Fleet today. What it amounts to is that in this era of a technological boom many of our systems were designed and developed to state-of-the-art performance limitations, rather than including all of the other qualitative elements which are characteristic of an operationally effective system. An effective system as previously defined this afternoon, is a system that can

successfully meet an operational demand throughout a given time period when operated under specified conditions. The basic qualitative elements which contribute to this systems effectiveness, as Mr. Rohe pointed out in the last presentation, includes in addition to performance, - reliability, maintainability, compatability, operability, logistics supportability, human factors, and others. I would be wrong to state that these elements were not considered at sometime and in some way during the course of development or production of today's systems. However, I will state that the inclusion of these elements into system development was not adequately planned for, resulting in an ill-timed and fragmented approach to systems effectiveness. I believe this statement is certainly justified in view of the number of "get well" programs which are now underway with many of our major systems. Basically, the purpose of these "get well" programs is to retrofit effectiveness into the systems, however, "get well" programs actually accomplish little more than the incineration of funds which we could be using more productively elsewhere in our RDT&E programs. You cannot drill a hole in a black box and stuff in some reliability or add another black box and label it maintainability or compatibility, or paste on some operability.

What then is the solution to this problem of being able to provide operationally effective systems to the Fleet? Systems that will not only meet performance specifications but will operate when called upon to operate without the necessity of having contractor technicians, engineers, or PhD's available to keep them

going. There must be a solution. We may never find an infallible solution or a panacea to this situation -- but we must strive for one.

A solution to the problem cannot be achieved without the integration in design and development planning of the disciplines -- if you will -- which constitute system effectiveness such as reliability, maintainability, etc. We must break with the tradition of treating these as separate functional entities. In addition this integration process must be instituted at the conception of a system -- i.e. we must start early; at the beginning -- and the resulting plans refined throughout the entire development planning phase of the system. I submit that this integration early in the gestation period of a system should result in viable trade-offs between these disciplines and pure performance objectives. This permits the optimization of true operational effectiveness. However, I must qualify this submission slightly. I have to define what I mean by the "system" that I refer to. The system considered must necessarily be the <u>total</u> system. It must not only be comprised of the hardware black boxes we are going to eventually design and assemble but it must take into consideration the black boxes of other systems or sub-systems which may supply support or be supported. The eventual overall operational configuration must be considered which includes, in addition to equipment interfaces, such things as physical location, environment, both functional and physical, and mission requirements.

It is extremely difficult and nigh on to impossible to scribe a circle and state this is the total system, so permit me to take a simple-minded out by calling it the big picture or the integrated whole.

The Department of Defense and the Department of the Navy recently have taken steps to incorporate regulations and procedures in the RDT&E planning process to provide for this integrated, total system approach in the development of Naval Weapons and support systems.

In February of this year the Department of Defense promulgated a new directive which directs that all new or major modifications of existing Engineering Development or Operational System Development projects estimated to require cumulative RDT&E financing in excess of twenty-five million dollars, or estimated to require production investment in excess of one hundred million dollars shall include a Project Definition Phase or PDP as it is commonly abbreviated. This requirement may be specifically waived by written approval of the Director of Defense for Research and Engineering. Other projects may be required to include a PDP, in whole or in part, at the discretion of the Department of the Navy or as directed by the Department of Defense for Research and Engineering (DDR&E). The PDP is one of the formal steps in the development planning process during which preliminary engineering, and contract and management planning are accomplished in an environment that

encourages realism and objectivity.

The objectives of a PDP are to establish trade-offs within the mission and performance envelopes; establish firm and realistic specifications; precisely define interfaces and responsibilities; identify high-risk areas; select the best technical approaches; establish firm and realistic schedules and cost estimates; and achieve fixed-price or incentive contracts for the subsequent full-scale development phase of the project. The results of a PDP must provide an adequate basis to ensure that management decisions to proceed with or cancel or change projects are made on the basis of a total system and total cost basis, realistic schedule estimates and achievable performance specifications.

PDP is at least a partial solution to the poor planning, unrealistic schedules, unanticipated design changes, large increase in costs over original estimates and "get well" programs which unfortunately have been characteristic of the development of too many major weapons and support systems. Project definition has been achieved sooner or later on all <u>successfully</u> completed development projects in the past but the object of the project definition phase is to achieve this sooner rather than later and avoid the disruptions in schedules, increases in cost and losses in operational effectiveness that result from changes caused by tardiness in project definition.

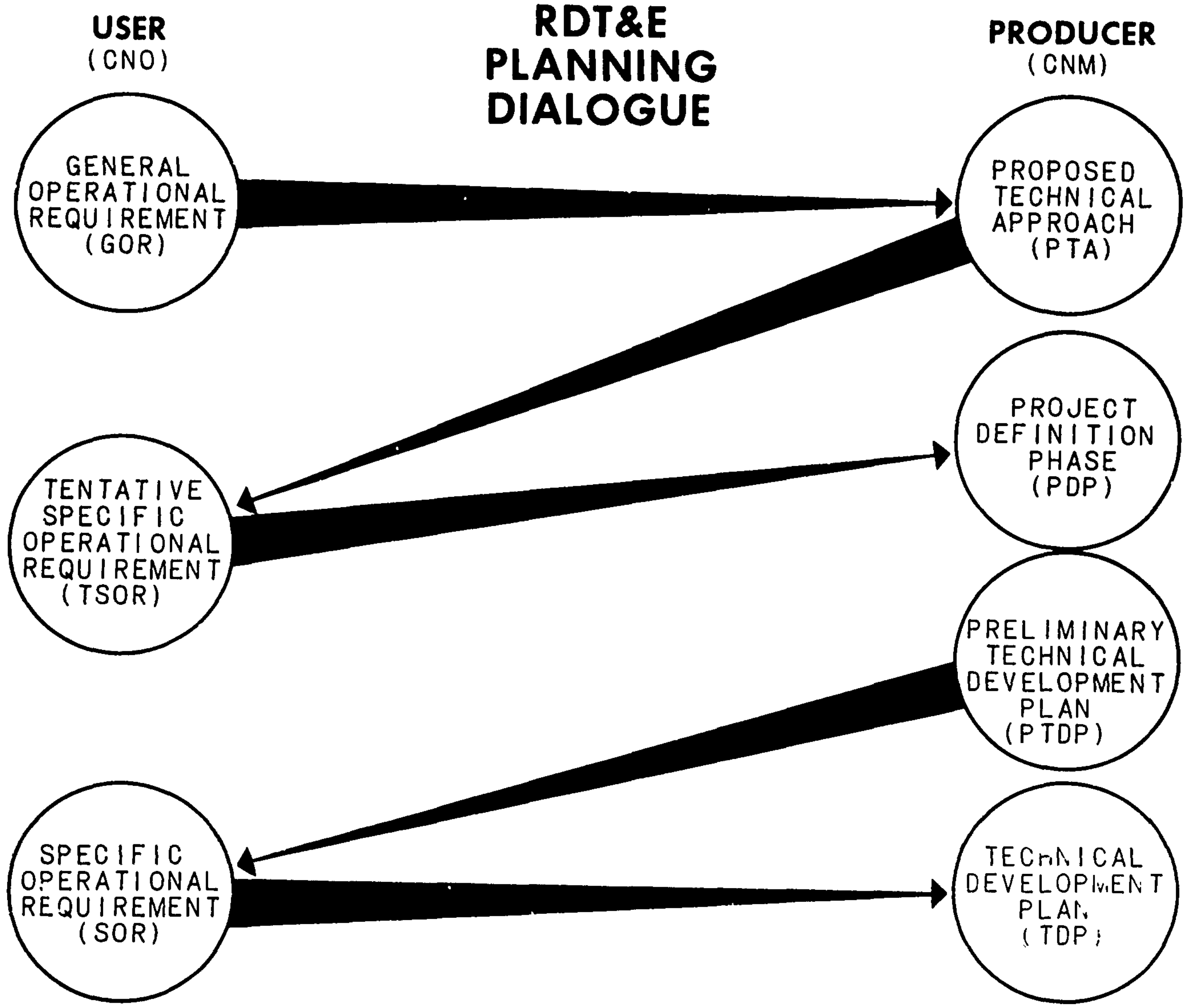
An objective of the PDP we are immediately and primarily con-

cerned with is the total system trade-offs which should be conducted during PDP. I would like to quote from the DOD directive on PDP concerning these trade-offs which states: Trade-offs shall be used to obtain, within the mission and performance envelopes, an optimum balance between total cost, schedule, and operational effectiveness for the system. In this context, total cost means the total cost of acquisition and ownership which includes development, production, deployment, operation, and maintenance; operational effectiveness includes all factors influencing effectiveness in operational use such as performance capability, reliability and maintainability; and system includes the hardware itself and all other required items, such as facilities, personnel, data, training equipment, etc. I think these statements adequately sum up what we are attempting to accomplish in obtaining total system effectiveness.

Of further significance is the fact that PDP studies are usually conducted by two or more contractors on a competitive basis for the prize of a multi-million dollar development contract if a full scale development is directed by DOD at the conclusion of the PDP. This competitive aspect of the PDP has the effect of producing thorough and complete trade-off studies which are considered so important at this point in the development process. If nothing else, it permits you to help us keep your competitors honest.

The PDP can logically be conducted any time subsequent to the establishment of a requirement for a system. This vugraph shows a simplified diagram of the Navy RDT&E planning process and where

USER—PRODUCER RDT&E PLANNING DIALOGUE



the PDP would fit in. The process shown is not necessarily classical and specific steps could vary somewhat; however, the basic process is representative.

The planning for an effective system should not begin with the PDP but should begin with the initiation of the development planning process. This can be seen by reviewing the RDT&E planning process.

RDT&E planning within the Department of the Navy is characteristically conducted as a dialogue between the user interest and the producer interest. The user interest is represented by the Chief of Naval Operations and the Commandant of the Marine Corps, as spokesman for the operating forces and the producer interest is represented by the Chief of Naval Material speaking for the Naval Material Support Establishment. This user-producer relationship is more analogous to a relationship between cooperating independent business organizations rather than to traditional military relationships. Parenthetically, I might add that there are times when we wonder if the analogy should be labor-management negotiation rather than buyer and seller. Plans are the result of negotiation between the two interests. Through this process the trade-offs should be made which will result in the maximum military capability for the Operating Forces possible within the limits of the resources available to the Naval Establishment.

The principal documents used in the user-producer dialogue are shown in the vugraph as the intermediate points in the flow diagram.

At first glance the impression is that the user interest levies

unilateral requirements -- based on pure military necessity -- on the producer interest. The actual process, however, involves a continuous interaction between operational requirements and their spokesman, and technical and scientific possibilities and their spokesman. It is one continuing iterative interchange. New formal requirements for weapons hardware more often than not have their genesis in new possibilities stemming from advancing knowledge and technology rather than from evolving military need or reassessment of old needs. These are the classes which Adm Ruckner in his remarks yesterday tagged as "pushed" operational requirements.

The Chief of Naval Operations is responsible for the preparation of a General Operational Requirement (GOR) for each functional warfare and support area. GOR's usually result from rather extensive long range strategic and tactical studies. These documents state, in relatively broad but significant terms, the capabilities the Navy needs within each area. For guidance in making trade-offs in weapons design the GOR should contain information on the relative importance of the various capabilities desired. In the past, performance specifications have been adequately stated in the GOR's, however, other considerations which comprise system effectiveness -- reliability, maintainability, etc. -- have not always been given adequate attention. Total system effectiveness and planning guidance for the total system must be provided as feasible. This is the beginning of system effectiveness planning that I spoke of earlier. Here is where we start thinking and planning for <u>total</u> system effectiveness.

The next step in the RDT&E planning process is the producer response to the GOR in the form of a Proposed Technical Approach (PTA). PTA's are developed by the Naval Material Support Establishment to propose technically feasible alternative methods of accomplishing objectives set forth in a GOR. The PTA should be fully responsive to the GOR, therefore, the quality of the PTA depends directly on the quality of the GOR. In addition to numerous other mandatory requirements of the PTA which are not of particular interest here, the governing OPNAV and DOD Directives require that the PTA should, to the extent that it can be determined or estimated, analyze and compare the operational effectiveness of the proposed alternate development approaches in terms of performance, reliability, operability, and maintainability and clearly indicate the basis of the comparision, such as previous experiments, extrapolation, or conjecture.

The user side of this dialogue then reviews what is presented in the PTA and makes a decision whether or not to pursue further study of the basic requirement. If further study is deemed appropriate a tentative specific operational requirement (TSOR) is issued to the producers which directs initiation of a study effort prerequisite to the establishment of a development program to attain the capability stated in the TSOR. The TSOR states the need for achieving a particular operational capability and outlines the identifiable characteristics necessary in a warfare system to fulfill the requirement. The TSOR defines the desired performance goals and provides additional information, such as the plans for

use, needed to weigh alternatives and make the trade-offs required to achieve an optimum system.

For major projects meeting the threshold requirements I mentioned a few moments ago, the study required by the TSOR usually takes the form of a Project Definition Phase. During the course of this study a Preliminary Technical Development Plan and a Specific Operational Requirement (SOR) are evolved.

The most important end product of the PDP is the Technical Development Plan or TDP. The TDP comprises the grand plan for the fulfillment of the requirements as originally spelled out in the operational requirements of the user. It is a complete and detailed description of the effort necessary to accomplish the development. The goal of a TDP is a balanced and integrated effort aimed at optimizing operational effectiveness, total cost, and early availability.

With the formulation of the TDP at the termination of the project definition phase the necessary total system planning for the full-scale development phase of the system is for all intents and purposes completed, however, during the full-scale development phase the TDP should be updated as required but if our planning has been adequate; necessary updating will be at a minimum.

The planning process leading to system development is well outlined with the requirements and guidelines covering the documentation required adequately defined in DOD and Navy Department directives. However, these directives alone do not insure that the guidelines will be followed and the requirements fulfilled in

planning the development of a system. To insure that requirements are met and that all elements of Systems Effectiveness receive thorough attention and adequate consideration by the Navy Material Support Establishment the Systems Effectiveness Branch of the Office of Naval Material analyzes and appraises all Proposed Technical Approaches and Technical Development Plans.

Operational Requirements originated by CNO also receive a penetrating review by this Branch to insure that the effectiveness requirements for the system are adequately included in these documents.

Unfortunately, this System Effectiveness Branch only recently came into being with the establishment of the Chief of Naval Material in December of 1963. Since that time, however, it has been the aim of this Branch to exert the leadership and guidance necessary to provide an effective, cohesive effort in the Navy Material Support Establishment towards systems effectiveness. With experience this leadership and guidance will become even more effective since the beneficial effect of cross-pollination among the various projects will be realized.

As you can see there are now requirements and procedures inherent in the development planning process designed to insure that total systems effectiveness is planned into the system under development. More importantly this planning is now forced to occur early in the development process which should insure that the desired system

effectiveness is designed and built in to the system. We must remember, however, that it takes people to implement the management procedures involved and needless to say the success of any management process is directly dependent upon these people. These people, and I refer to the people of industry as well as Navy people, must be oriented towards and dedicated to the total system effectiveness approach to development planning and not to any one element of this discipline in the manner pure performance capability was in the past. We must also avoid including elements such as maintainability for maintainability's sake or reliability for reliability's sake just because its required or because its the vogue. Each of these elements must be weighed and carefully traded-off for each particular system under development. The weights applied to these elements will of course have to vary between systems in order to appreciate the different functions of these various systems.

Of more significance than the fact that these weights vary is the nature of the control of the variance. Although complex in detail, the general rule is readily stated. How much value is this function to the accomplishment of the system's mission as against the other system functions? The answer to this question provides the weighting criteria. In our plannings as indeed all of our efforts in the military-can have but one end objective - the military mission. It therefore is necessary that our planning have as its focus the military mission of the system. This requires that our planning weighting factors also be determined by mission considerations.

COST FACTORS IN SYSTEMS DESIGN

PRESENTED AT THE

NORTHEASTERN STATES

NAVY RESEARCH AND DEVELOPMENT CLINIC

PHILADELPHIA, PENNSYLVANIA

19 NOVEMBER 1964

Mr. John W. Stone
Office of Naval Material
Department of the Navy

COST FACTORS IN SYSTEMS DESIGN

I would like to discuss some of the factors relating to cost effectiveness and the influences of these factors on systems design. The previous papers have discussed various important elements of system effectiveness, all of which relate to and affect one another. It is this inter-relationship of these various elements which form the basis for naval systems decision making. Cost is another major element to be considered in the decision making process. Cost is probably the one element, or ingredient, when properly weighed, becomes a yardstick which will bring all elements into proper focus.

Webster defines "COST" as "THE LOSS OR PENALTY INCURRED IN GAINING SOMETHING." Cost is, therefore, an exchange or trade-off. It is this trade-off connotation, which is the key or measure used in determining effectiveness.

System Effectiveness has been defined as "THE PROBABILITY THAT THE SYSTEM WILL OPERATE SUCCESSFULLY WHEN REQUIRED UNDER SPECIFIED CONDITIONS OR ENVIRONMENT." Mr. Rohe, in his discussion of engineering integration, expressed the term in its gross sense by using the formula: $E_s = PAU$ (Figure 1). "E_s", system effectiveness, being the product of; "P", the <u>p</u>erformance or system's capability; "A", the <u>a</u>vailability or the fraction of time the system is ready and capable of performing its mission; and "U", the <u>u</u>tilization or fraction of the performance capability actually utilized for a specific application in a specified environment. Therefore, an increase in one or more of the elements of <u>p</u>erformance, <u>a</u>vailability

$$E_s = PAU$$

E_s IS SYSTEMS EFFECTIVENESS

P - PERFORMANCE

A - AVAILABILITY

U - UTILIZATION

FIGURE 1

or utilization will have an attendent increase in the effectiveness of the system. An increase in systems effectiveness means we have gained something. For this gain there has also necessarily been corresponding loss or penalty incurred ---- a cost. What are these costs and how do they affect the system? This provides the alternatives or trade-offs, which are the inputs required by the decision maker.

The injection of cost provides a new dimension to the term systems effectiveness and establishes it as more than a sterile, academic exercise. To distinguish this new discipline, we can term it cost effectiveness. Cost effectiveness can be defined simply as the ratio between systems effectiveness and its attendant costs. Expressed in gross terms the formula is:

$$E_c = \frac{PAU}{C_a + C_u} \qquad \text{(Figure 2)}$$

E_c being cost effectiveness which is the previously defined systems effectiveness (the product of performance, availability and utilization) divided by the total cost. The total cost is expressed here as the sum of C_a, the cost of acquisition, plus C_u, the cost of utilization or as it is sometimes referred to as the cost of ownership

The denominator could just as well have been expressed as total program cost; however, I have separated the total cost into these two broad categories to emphasize the need to insure that all costs are considered. Figure 3 illustrates what is included in these categories.

Cost of acquisition, as stated before, is the total dollar cost of development and production. Development costs include all dollar costs associated with; operation analysis, system definition, system design,

$$E_c = \frac{PAU}{C_a + C_u}$$

E_c – COST EFFECTIVENESS

C_a – COST OF ACQUISITION

C_u – COST OF UTILIZATION

FIGURE 2

C_a COST OF ACQUISITION

DEVELOPMENT
- OPS ANALYSIS
- SYST DEFINITION
- SYST DESIGN
- HDW DESIGN
- TEST & EVAL

\+

PRODUCTION
- PROCUREMENT
- MANUFACTURE
- INSTALLATION
- TEST
- TRAINING

C_u COST OF UTILIZATION

OPERATIONS
- PERSONNEL
- FACILITIES
- UTILITIES
- SPECIAL INPUTS

\+

MAINTENANCE
- PERSONNEL
- FACILITIES
- SPARES
- LOGISTICS
- DIAGNOSTIC AIDS

\+

EXTERNAL COSTS DUE TO FAILURES

FIGURE 3

hardware design, test, and evaluation. Production costs include all dollar costs associated with; procurement, manufacture, installation, test, and training.

Cost of utilization is the average annual dollar cost of operating and maintaining the system, including the external cost of its failures, multiplied by the number of years of useful life. Operational cost is the long term annual dollar cost of system for operating personnel, facilities, utilities and special inputs required. Maintenance cost is the long term annual dollar cost of system maintenance personnel, facilities, spare components, logistics and diagnostic aids, etc. Also, we must not forget the costs which are external to the system but are as a consequence of system failures.

By proper emphasis of all cost elements, the total cost becomes meaningful to the decision makers. Too often decisions concerning new systems have been made considering only the estimated cost to develop and procure. With our eye focused on this cost of acquisition we find our astigmatism has blurred the cost of utilization aspect. From a development and production standpoint the cost effectiveness of a particular system may be outstanding. However, without adequate attention to the cost of utilization the Fleet can find itself with a system which is plagued with excessive operating and maintenance costs. Corrective action is usually expensive and more often than not the system will still have a greatly reduced effectiveness. Such a case can be the result of the cost effectiveness not including all the trade-off's necessary to make the proper decision.

I would like to illustrate by setting up a hypothetical example. For this example, I have chosen two similar systems and labeled them system "x" and system "y", respectively. If we ignore the cost context, the System Effectiveness is determined by the formula $E_S = PAU$. (System Effectiveness being the product of Performance, Availability and Utilization.) Figure 4 shows the System Effectiveness without the element of cost as being 460 for system "x" and 612 for system "y". It is, of course, assumed that the calculations for both systems are to a common base of total mission capability of 1000. Also let us assume the unlikely situation, where the confidence factors are equivalent. Therefore from analysis of the system effectiveness we would elect system "y" because of the margin 612 has over 460.

Let's look at what happens when we consider the cost effectiveness of only cost of acquisition. To do this we ratio the effectiveness of systems"x" and "y" by the cost of acquisition. As I stated before, cost of acquisition is the total dollar cost of development and production. Going back to our hypothetical example, the cost of acquisition for system "x" is $5.0M while for system "y" it is $6.0M. The penalty to acquire the additional capability of system "y" over system "x" is seen to cost $1.0M. Figure 5 ratios the previous "x" and "y" values of system effectiveness by their respective costs of acquisition. The resulting cost effectiveness has an index of 92 for system "x" and 102 for "y". Cost effectiveness analysis, from the cost of acquisition standpoint, would also select system "y" as being superior; as did the previous system effectiveness model.

SYSTEMS EFFECTIVENESS (E_S = PAU)

SYSTEM "X"
$E_{SX} = 460$

SYSTEM "Y"
$E_{SY} = 612$

ASSUMPTIONS - BOTH SYSTEMS HAVE:

1. TOTAL MISSION CAPABILITY 1000
2. EQUIVALENT CONFIDENCE FACTORS

FIGURE 4

COST EFFECTIVENESS $E_c = \frac{E_s}{C_a}$

(BASED ON COST OF ACQUISITION ONLY)

SYSTEM "X"	SYSTEM "Y"
$C_{ax} = \$5\bar{M}$	$C_{au} = \$6\bar{M}$
$E_{cx} \frac{460}{5} = 92$	$E_{cy} \frac{612}{6} = 102$

FIGURE 5

Up to here we have neglected our cost of utilization or cost of ownership. Cost of utilization, as given before, is the average annual dollar cost of operating and maintaining the system, including the external cost of its failures, multiplied by the number of years useful life.

Let's take our hypothetical "x" and "y" systems and see the effect the cost of utilization has on cost effectiveness. System "y" with its superior capacity has a cost of utilization of $8M. System "x" has a cost of utilization of $4M. Figure 6 incorporates these values into the cost effectiveness formula we find system "y" with an index of 43.7 while system "x" enjoys a larger value of 51.1. By considering the total cost, we find the system with the better cost effectiveness is system "x", not system "y" as previously indicated.

This is a very crude example. However, as ever increasing requirements are placed on us to design systems with quantum jumps in systems performance, we cannot overlook any of the factors of cost. We must not only ask ourselves if we can afford the system from the development and production aspect, but also can we afford the cost of ownership. The old saying "It is not the initial cost but the upkeep" is just as true for naval systems as anywhere else.

We are accustomed to thinking of cost as being dollars. However, dollars are only the medium of exchange and as such dollars are not true resources. Commander Sargent expresses cost as having four real coins. The four real coins of cost are:

(1) Manpower
(2) Material
(3) Facilities
(4) Time

COST EFFECTIVENESS $E_c = \frac{E_s}{C_a + C_u}$

(BASED ON TOTAL COST)

SYSTEM "X"	SYSTEM "Y"
$C_{ux} = \$4\overline{M}$	$C_{uy} = \$8\overline{M}$
$E_{cx} = \frac{460}{5+4}$	$E_{cy} = \frac{612}{6+8}$
$= 51.1$	$= 43.7$

FIGURE

There is a degree of exchange available among these four coins or resources. The optimization of effectiveness must take cognizance of these available trade-offs. Cost effectiveness is a measure of how well we spend these four real coins of cost for the purpose of gaining in system effectiveness.

To conclude, I would like to point out that all of the aspects of cost are under the cognizance of the systems designer, whom I enjoin to insure that proper consideration is given to all of the cost factors. Only by so doing, are the necessary inputs available for proper system decisions. We must have systems which have a reasonable cost of ownership.

MAN PARAMETERS IN SYSTEM SUPPORT

PRESENTED AT THE

NORTHEASTERN STATES

NAVY RESEARCH AND DEVELOPMENT CLINIC

PHILADELPHIA, PENNSYLVANIA

19 NOVEMBER 1964

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MAN PARAMETERS IN SYSTEM SUPPORT

In recent years we in the Armed Forces have been referring to our warfare systems as man-machine systems. That we have combined men and machines in warfare has been true since man discovered the effectiveness of the simple lever machine called a club. Why - then - do we use the hyphenated expression, man-machine, now as though the combination were a new discovery? Is there really something new or is this simply a change in mode of expression?

I would submit that there is indeed something very new and different which, although subtle and not always fully understood by the users of the expression, "man-machine systems", is fundamental and MUST be thoroughly understood by all connected with the military development process, particularly those decision-makers to whom we sometimes loosely refer as management.

During the days of club, sling, spear and arrow each fighter had his own machine. This machine was essentially a direct extension of the individual's capability. With it he could hit harder and further than he could without it. As warfare technology evolved, range and hitting power increased. The machine changed from the simplest level to ever more complex devices often requiring more than one man to operate. This evolutionary process continued along the same track until ranges exceeded man's capability to put the machine on target with the unaided eye. It therefore became necessary to extend his ocular capability by the use of optical systems. Even as late as the early days of World War II - machines, as complicated as they were with

respect to the war club, were still just extensions of man-s capability to see and to strike. Stimuli were perceived by a man and he initiated the strike. The very control, although sometimes machine assisted, was still done through man's own motor control mechanisms.

Two significant technological innovations in our time are changing the basic evolutionary pattern which has existed since before recorded history. I say "are changing" because their full impact has not yet been felt. Indeed, early applications were in the context of the old idea of being used simply as an extension of man's capability. The first of these, radar, illustrates my point quite well. Its very name, radar, was derived from its application, radio direction and ranging. We were merely extending our ocular capability through electromagnetic means because of its range superiority over optical means.

Although not generally recognized, the birth of the new era, symbolized by the term man-machine systems, occured when the technologists produced the automatic tracking and fire control or gun laying radars. This was quickly followed by the second technological innovation, high speed electronics computers. With these machines we had devices which could replicate the logic process which heretofore had been the exclusive domain of man. No longer were machines simply the sensory and physical extensions of man.

With the invasion by the machine into the logic process, hitherto exclusively man's, the relative roles of man and machine have undergone a subtle but nonetheless fundamental change. No longer can we regard man as an entity apart from the system - an entity who operates

maintains or controls the machine. Rather he is explicitly a part of the system contributing those capabilities which are uniquely his. Thus in theory at least we now have man-machine systems with the man assigned those tasks which he can do most effectively and and efficiently and the machine assigned those tasks which it can do most effectively and efficiently.

This nice, logical rationale provides a philosophy for our systems concepts. There remains one problem -- implementation. Einstein's equation is sheer simplicity, $E = MC^2$. But the problems attendant to the exploitation and implementation of the concept represented by this simple equation are too well known to be recited here. It has been said that simple solutions stem only from simple problems. Like the Einsteinian concept, ours poses anything but a simple problem.

I shall not attempt to discuss the whole problem. Rather I'd like to confine myself to one aspect of the problem, man in the system.

Much as it may bruise individual egos, man is subject to the machine even as the machine is to him through the interactions which take place in today's complex systems. Certainly man's judgement must prevail and in a sense can be considered to control since the machine does not possess intellect. However, we must not lose sight of the fact that even this "man-only" attribute can be and is influenced to a remarkable extent today by the method of processing and manner of display of the processed data by the machine.

Quite apart from considerations of force levels or technological

advances, the realities of man-machine interactions dictate a much harder and more studied approach to the man and his functioning in the system. Lest I mislead you, let me make it clear that I am not referring solely to the lower skill levels who obviously fulfill the transfer-function between segments of the system. I refer also to the Commander. Due to his displacement from the data source, he is actually subject to incremental machine decisions to a greater extent than those who are lower in the hierarchy of decision making. Therefore he must be assured that the maximum capability of both man-segments and machine-segments are brought to bear by way of providing the best possible inputs to <u>his</u> level of function in the system. As we face threats of ever higher velocities, this becomes the more pressing since the Commander has a diminishing reaction time in which to make his decision. He thus becomes more dependent upon the incremental decision-making at lower echelons in the system.

In those echelons which are purely machine, the task of validating is relatively easy. We know the machine can make only those decisions which a man has made previously. Further these were carefully checked and rechecked in an environment apart from battle stress. But -- these machine-segments have an Achille's heel. In the computer fraternity they pithily express it as "garbage in - garbage out". No matter how valid the programming, the quality of output can be no better than that of the input.

Frequently these inputs come from the man-segments. These are much more difficult to validate. We must consider both the quantitative and qualitative variances in performance among the specific individuals

who may be assigned the task from time to time as well as the variances of given individuals in time. To add to the problem, we are woefully lacking in the means for measuring the performance and capabilities of the man. Neither do we know enough about how and why he functions. We cannot give our system designers anything approaching the completeness of the capability description we provide for the machine segments he uses. This area of effort, termed Human Factors Engineering, must be greatly expanded from present effort levels if we are to achieve maximum systems effectiveness.

Within the context of our philosophical concept Human Factors Engineering is a very broad area of concern encompassing such diverse disciplines as the full gamut of the behavioural sciences, phsiology, anthropometrics and psychometrics in the research and development sphere. In an applied Engineering sense, it includes the area which we have traditionally referred to as Personnel Management and Training. Actually, one can conceive of the Personnel and Training people as being the producers of the man-modules for our systems. It is to them that our systems engineers look for the man in the systems. It is to them also that the systems engineers look for the descriptive specifications of the man available for incorporation into the system.

Herein lies the problem. While there is a positive effort to provide quality control in processing the product and in selection of the raw material input, the random and parenthetically frequently accidental nature of the origins of the raw material poses real difficulties. As a result, descriptive specifications are given in

very broad parameters.

This situation is aggravated by our lack of real understanding as to how and why this raw material, man, functions. Neither do we have the attendant measuring systems for this functioning. We point with pride to the fine tolerances to which we can produce machine-elements. We measure them with micron exactness. Then we ask the system designer to combine them with man-elements which we describe as an average man with an 8th grade mentality. What precision! What an exquisitely defined measurement scale! -- and management says, "Give us systems effectiveness."

That we need systems effectiveness, particularly in the military in these days of hypervelocity weapons, is a reality that is incontrovertable. However, the achievement of system effectiveness is highly problematical until and unless we can solve the problems of the man parameters in system support. Our technology has reached a point where we may no longer hide our relative ignorance of how and why man functions behind the idea of the adaptability of man. That we are straining the boundaries of this adaptability is evidenced by the incidence of cardiac and neurasthenic casualties among our military. It is also evidenced by the fact, as reported by the FAA, that 80% of our aircraft accidents are attributable to pilot error. We must stop using adaptable man as the multi-purpose gap-filler between machines. We must strive for the design goal which uses man with all deliberateness to perform those functions in which he is superior to the machine rather than to perform those functions which we don't know how to design a machine to perform, often with little regard to either the level of quality or the quantity of tasks assigned.

In order to reach the design goal we must first learn far more than we now know about how and why a man functions. We must learn how to measure the parameters which describe these functions. We must acquire the capability to describe exactly what combinations of man-functions are (or potentially are) in our available inventory together with the distributions of these functions. Until we are able to provide adequate man parameters to our systems designers, the probabilities of true systems effectiveness will continue to be quite low and high systems effectiveness will be more accidental than calculated. Low systems effectiveness, I submit, is the situation today. Although not so reported, this is manifested in myriad reports.

These reports use such terms as "too complicated machines," "inadequate training," "above the heads of our people," "can't be maintained," etc. These, if you will, are symptoms. These demonstrate our inability to fit the available man-modules to the system. I would offer as evidence of this contention that, in almost every case, we are able to provide a combination of man-modules and machine-modules that does function effectively. More often than not we ascribe the difference between the successes and failures to such things as leadership, luck or, in some cases, a unique set of circumstances. In any case, one effective system case is evidence that the system can work effectively.

If you will think back on the systems each of you has been concerned with, I believe you can see a characteristic pattern. In our egocentric way, we attribute our successes to the quality of

the men in the system and our failures to the inadequacies of the machine in the system. We explain the "why" of the machine inadequacies quite exactly. But--do we explain the "whys" of our man-attributed successes with the same exactness? Of course we don't. We don't know how. "The leadership was better." "A certain technician knew more." How much better? How much more? These are characteristics of our man-machine systems that we haven't yet learned how to quantize. In the absence of this capability we are constrained to use comparative verbiage which is singularly unprecise and subject to value changes in the communication process.

Quantizing the man function then becomes the core problem to our systems effectiveness effort. What do we do about the Man Parameters in System Support? To me, the solution is quite clear. First, management - and explicitly Armed Forces Management - must admit to not being the fount of knowledge in the appraisal and evaluation of the man-function - admit that at best we are using boilermaker measurements on watch movements. Am I really overstating? Look at the three-element O, S & U. system we use in evaluating our civil-service personnel. Look at theirs or our own job-descriptions. Look at Efficiency Ratings or Fitness Reports. How many of the latter have you made out against the job requirements or billet description much less against any empirical performance standard? Certainly we do the best we can with the tools we have available. But, these tools don't begin to approximate the performance standards and measures we employ for machine-segments of our systems.

If we are to resolve the problem, to me the most vexing facing top Military Management today, we must undertake a program of study

and analysis of the man parameters in systems far greater than that which we currently have underway. We must close the gap in our understanding and measurement of the man-parameters. We must initiate and support efforts in scientific study which will lead to an understanding and measurement of the man akin to that we possess for the gear, the electron or red fuming nitric acid.

To this end, a number of projects are underway in the Navy. In an attempt to get a handle on the problem, the Bureau of Ships supported by the Office of Naval Material has initiated a project called TRIM. TRIM is an acronym for Training Requirements Information Management. TRIM is a systematic approach to the codification, recording and collection of training requirements data and personnel resource data in terms of training. Perhaps the most significant aspect of TRIM is that its design concept takes into account the gross nature of existing measures of man parameters. As a result the matrices in the system have been designed to provide for ultimately more refined measures without necessitating a new data system.

A second Navy project, which I'd like to cite is the effort under the sponsorship of the Chief of Naval Personnel referred to as the New Developments Human Factors Program. This is a rather broad-gauged effort to define the problem and provide solutions in the personnel management and training, or if you will, production processes for our man-modules.

In a more penetrating manner but with somewhat narrower scope, the Naval Aviation Development Center, Johnsville, Pa. and the School of Aviation Medicine at Pensacola, Fla. have been probing into man-

measurements peculiar to the aerosphere and the Naval Medical Research Institute at Bethesda has done similar work in the hydrosphere. These latter efforts have been dominantly in the bio-medical field.

NASA and Air Force have probed somewhat more deeply into the psychological aspects of man's behaviour in the Mercury and APOLLO projects. This work has produced valuable spin-offs for terrestrially limited systems but is focused principally at a highly specialized situation which can afford highly specialized men and environmental controls.

However, the vast bulk of our military systems must use the so-called average man. Further, highly specialized and very expensive artificial environments are simply not economically feasible for them.

Therefore we must learn more about how and why this average man performs. We must learn how to measure and predict this performance. The measures and these predictions may then be used by the system designer as the descriptive parameters of the man in the system. Then and only then can we hope to achieve overall systems effectiveness in our military systems.

THE KEY TO DEVELOPMENT PAY OFF

REMARKS OF

REAR ADMIRAL E. A. RUCKNER

AT THE SYSTEMS EFFECTIVENESS PANEL

THE WESTERN STATES NAVY R&D CLINIC

MONTANA STATE COLLEGE

BOZEMAN, MONTANA

22 July 1964

Dr. Trumbull, members of the Systems Effectiveness Panel of the Western States Navy R&D Clinic, ladies and gentlemen,

The subject matter of this session represents the most comprehensive, and hence most critical, problem challenging the Research and Development community today. It is axiomatic that technological advances are of little use if the systems they produce are not effective. As the Deputy Chief of Naval Material for Development, my concern is that all naval development and particularly those combinations of men and machinery which we term warfare systems provide to our fleet a maximum capability in fulfilling their national defense role. This capability varies directly with the systems effectiveness of the man-machine combinations.

Having established myself as being for motherhood and against sin, let's look behind the platitudes to see what are their implications. Are these just brave words -- or -- is there a key which will open the door to development pay off?

If you have inferred from the foregoing that I consider that we are not making technological progress, disabuse your minds of the thought. However; if you infer that I consider that we are not realizing an optimum payoff from the ever accelerating curve of technical progress, you are quite correct. This I attribute in a large measure to overextension: - overextension of the men in the system and overextension of the men designing the system. The dangers attendant to overextension are not unknown.

History is full of examples of failures and defeats caused by people who were in too much of a hurry. Humans have a tendency to become

so enchanted with progress that they fail to recognize the dangers of overextension. Military commanders are aware of the necessity to consolidate their positions after a more forward, before striking out again on a new advance. Chess players are aware of the fallacy in moving too quickly into enemy territory without adequate consolidation of home defenses. Businessmen can testify to the dangers of over committing themselves in many of their activities. The stock market crash of 1929 shows what happens when "progress" is not based on a firm foundation.

To say to an audience such as this that technology is advancing at a tremendous rate is little like carrying coals to Newcastle. But it is a fact which we must not overlook despite its familiarity. In an effort to keep pace with technology, we -- industry and the military -- are feverishly extending ourselves. Even though people ARE adaptable, there has been little basic change in them over the centuries. Yet we are being called upon to match this relatively unchanging man to a virtually exploding technology. Adaptability alone cannot bridge the widening gap between the two without stretching the people beyond their tolerance.

As we try to keep pace with technology, our efforts produce ever more complex combinations of men and machines. The slope of the technological capability curve far exceeds that of the people capbility curve. The result is overextension of the "man in the system". In addressing ourselves to this problem, we must concentrate on correcting the complexities of the machine segments of the system and on examination of the place of the man in this man-machine system. Failure to do

so will result in increasing inability to obtain sufficient quantities of personnel trainable to match and cope with the complexities of modern warfare material, which for reasons I do not fully understand, we call "sophisticated" systems.

Sophisticates, in a social sense, are not usually associated with the production of worthwhile results. As defined by Webster, the very sophisticate is to deprive of genuineness, naturalness, or simplicity; to disillusion; to make worldy-wise. Yet we refer to these complex systems of machines and overextended men as sophisticated. Could it be because we have deprived them of their simplicity?

Certainly in the areas of missiles and electronics, in particular, our fleet systems do not represent simplicity. To say that these have been deprived of their simplicity is difficult. The treats which our systems must counter ARE complex. Solutions to the problems these threats pose are complex. But this does not give license for complexities unlimited.

Both the military and industry have contributed complexities which are of challengeable merit. Both must ask themselves the question "Is this really necessary or worthwhile?" We must vigorously resist the introduction of additional features, functions and other complicating mechanisms which are not vital to the mission effectiveness of the system. We simply cannot afford what Dr. Fubini has termed the American syndrome, the penchant for complex gadgetry.

Both complexity and gadgetry provide additional opportunity for failures to occur. These failures can be machine failures or they can be man failures stemming from the sheet complexity of his work

environment. As a result today's sophisticated systems show a tendency toward undependability. They are marvels of technological ingenuity. But -- this is little comfort to the Commander unable to complete his mission because the beautifil beast cannot be relied upon to work when and where needed.

Undependability stems from many contributing factors such as shortcomings in reliability, maintainability, compatibility, human factors, logistics supportability, etc. All of these qualities of systems are fairly readily understood and quite well appreciated both by military and industry. But -- understanding and appreciation are not enough. We must devise valid means for measuring these qualities. This is necessary so that we can assure dependability by effecting real communication between the military and industry in specifying mutually acceptable and attainable contract requirements, and in insuring that these specified qualities of dependability are in fact achieved by the contractor.

It would appear that in our haste to keep up with technology, we have not expended the time or effort needed to consolidate and stabilize the technology we have exploited. This is not to say that the problem has been ignored. On the contrary far more attention has been given to system effectiveness than can be readily measured. Each contributing designer in a system is conscious of the need. In his own area he designs to the end of realizing dependability. This is not enough.

We must insure that <u>all</u> of the foregoing factors are mutually optimized on a total system basis. This must be done <u>before</u> we provide

the results to the fleet.

In doing this, we must recognize and fully face a basic anomaly of the situation. Technology is a dynamic force. How then can it be consolidated?

I would suggest that it can be consolidated in the same manner in which it can be measured--at a discrete point in time. We must pick this point and stay with it. Then both the military and industry must resist the temptation to inject incremental advances in the course of a development. We must defer these goodies to a subsequent generation. There are those who will take issue with this position. They say that this assures obsolesence upon delivery. I submit that this argument is more hypothetical than real. Nevertheless, even given that there is some validity to the argument, I would submit that our military posture is strongest when systems have mission dependability. This holds even without the latest theoretical increment of capability. For instance, a destroyer with a sonar system reliability of .9 and a probability of detection of .8 at a maximum range of 10,000 yds is of more use to the ASW Commander than one with a .5 reliability and a 12,000 yd max range even assuming comparable probabilities of detection. Consider also that low reliability can normally be expected to be accompanied by reductions in the other qualitative factors that I've cited. Recognizing the validity of this type of reasoning, the Navy is taking a hard look at its R&D Program.

We in the Office of Naval Material call this examination System Effectiveness analysis. We are studying the trade offs between technological advances and consolidation of technological position.

As we learn more in the skills of quantizing the factors which to go make up Systems Effectiveness, the examination will be even more rigorous. This may well result in a reduction of the number of systems under development but with a more intensive effort on those remaining.

We are persuaded that the key to development pay-off is the successful consolidation of position through a viable approach to Systems Effectiveness. The analysis and review by the Office of the Secretary of Defense under Project Definition Phase and under Configuration Control require some such approach. Further we need to pursue such a course to permit real calculation of risk. Since last December 2nd, all Proposed Techincal Approaches, Technical Development Plans, Specific Operational Requirements and Advanced Development Plans have received rather penetrating review by my Systems Effectiveness Group. This review will be intensified in depth with a view toward recommending the elimination of incremental improvement effort that is not completely justified by urgent military worth considerations. Our goal is to insure that all factors of Systems Effectiveness receive thorough attention and adequate consideration before the production phase and fleet introduction.

This may sound like a hardnosed approach. It is not intended to be. However, it is intended to be a hard-headed approach. There simply is no substitute for effectiveness in a system - for - if the system does not have mission effectiveness, where is the pay-off? The pay-off comes only on effective results. So, we in the Office of Naval Material intend to take a page out of the book of some of the good people of Montana. They tell me that no matter how well configured he may be,

the sterile ram gets shot and, like ewes, rapidly become mutton. I don't know what boiled missile tastes like or roast radar -- but I'm willing to find out.

SYSTEMS EFFECTIVENESS ASSURANCE MANAGEMENT

PRESENTED TO PERSONNEL OF

THE NAVAL MATERIAL SUPPORT ESTABLISHMENT

NOVEMBER 1964

Dr. Leslie W. Ball
Boeing Aircraft Corp.

In recent years many cults have arisen each of which has indicated a real need for management action to get system effectiveness. The time has come to relate all these cults to each other and to relate them to the basic management objective. The 1st vugraph "Integration of Assurance Cults" identifies some of the major product characteristic cults and some of the major program management cults. It states that both types are only subordinate factors in achieving the basic objective of system effectiveness and consequently they should be treated as vital but subordinate segments of an integrated system effectiveness assurance management system.

No one questions the objective of system effectiveness assurance. Many people do question the need for a formalized management system to achieve ~~these~~ objectives. This resistance must be faced squarely and understood. The 2nd vugraph "Yearning for Anarchy" summarizes the opposition to any management system that constrains the activities of people. It raises the vital question "Why should we annoy everybody with a management system?" Since the purpose of management is to get things done through people we must have a good reason for doing anything contrary to the nature of people.

The 3rd vugraph "Justification for Discipline" states two major reasons for a formalized management system. It conceives that the system does seek to control the activities of people but only to the extent necessary to assure the two major objectives of requirements optimization and experience retention. Requirements optimization in-

INTEGRATION OF ASSURANCE CULTS

PRODUCT CHARACTERISTIC CULTS

SEVERAL CULTS HAVE DEVELOPED FOR ASSURING ACHIEVEMENT OF A SINGLE PRODUCT CHARACTERISTIC SUCH AS RELIABILITY, OPERABILITY, SAFETY OR MAINTAINABILITY

PROGRAM MANAGEMENT CULTS

SEVERAL CULTS HAVE DEVELOPED FOR ASSURING APPLICATION OF A SINGLE TECHNIQUE SUCH AS VALUE ENGINEERING, PERT OR CONFIGURATION MANAGEMENT

BASIC OBJECTIVE

THESE PRODUCT CHARACTERISTICS AND TECHNIQUES ARE ONLY SUBORDINATE FACTORS IN ACHIEVING THE BASIC OBJECTIVE OF SYSTEM EFFECTIVENESS — CONSEQUENTLY THE CULTS THAT PROMOTE THEM SHOULD BE TREATED AS VITAL BUT SUBORDINATE SEGMENTS OF AN INTEGRATED

SYSTEM EFFECTIVENESS ASSURANCE MANAGEMENT SYSTEM (SEAMS)

WHY AN ASSURANCE MANAGEMENT SYSTEM

YEARNING FOR ANARCHY

MAN HAS AN INHERENT YEARNING FOR FREEDOM FROM CONSTRAINT ON HIS ACTIVITIES.

SUPPLIERS WISH TO BE FREE FROM CONTRACTOR PURCHASE ORDER CONSTRAINTS.

CONTRACTORS WISH TO BE FREE FROM CUSTOMER SPECIFICATION CONSTRAINTS.

PROGRAM DIRECTORS WISH TO BE FREE FROM DOD DIRECTIVE CONSTRAINTS.

DOD WISHES TO BE FREE FROM CONGRESS BUDGET CONSTRAINTS.

SO WHY ANNOY EVERYBODY WITH A MANAGEMENT SYSTEM?

VUGRAPH 2

WHY AN ASSURANCE MANAGEMENT SYSTEM

JUSTIFICATION FOR DISCIPLINE

ANARCHY DOES NOT ASSURE THAT INDIVIDUAL REQUIREMENTS ARE COMPATIBLE WITH TOTAL SYSTEM EFFECTIVENESS.

ANARCHY DOES NOT ASSURE THAT LESSONS LEARNED FROM PREVIOUS EXPERIENCE WILL BE RETAINED AND APPLIED TO NEW WORK.

AN ASSURANCE MANAGEMENT SYSTEM CONTROLS THE ACTIVITIES OF PEOPLE BUT ONLY TO THE EXTENT NECESSARY TO ASSURE:

(A) REQUIREMENTS OPTIMIZATION

(B) EXPERIENCE RETENTION

IT DOES SO BY DISCIPLINING ACTIVITIES THAT ARE CRITICAL TO THESE OBJECTIVES.

VUGRAPH 3

volves techniques of system analysis. Cdr Sargent has published some excellent papers on the subject and it will be dealt with in more detail at the second symposium on Nov 17.

In regard to experience retention every project shows that in fact we do repeat mistakes and do so over long periods of time. For example, at a recent BIMRAB meeting a presentation on aircraft safety summarized the causes of loss of property and life in a modern jet aircraft. Then the speaker showed a picture of a 30-year old biplane and made the key point. The point was that the same cause of failure for the modern jet that had occurred, had been analyzed and understood 30 years ago.

Requirements optimization is achieved by disciplined decision making based on system analysis techniques. Experience retention is merely the application of the discipline of the scientific method to management problems.

The 4th vugraph "Definition of Discipline" identifies this word with the training motivation commanding and auditing of people. The management system does not seek to provide even these types of formal discipline except for those activities that experience has shown to be critical to achieving system effectiveness. Also this vugraph summarizes the three vital steps in the management system. Briefly they are:

(1) Critical activity identification

(2) Resources development

(3) Resources application for each critical activity

This description corresponds with the definition that "The business of

WHY AN ASSURANCE MANAGEMENT SYSTEM

DEFINITION OF DISCIPLINE

RELATIVE TO PEOPLE THE TERM "DISCIPLINE" MEANS PROVISION OF AND DEDICATED RESPONSE TO:

TRAINING	**MOTIVATION**
COMMAND	**AUDIT**

FOR THOSE ACTIVITIES THAT ARE CRITICAL TO ACHIEVING SYSTEM EFFECTIVENESS.

RELATIVE TO THE MANAGEMENT SYSTEM DISCIPLINE MEANS:

1. FORMAL IDENTIFICATION OF SYSTEM EFFECTIVENESS CRITICAL ACTIVITIES **(SECA)**
2. FORMAL RESOURCES DEVELOPMENT THROUGH EXPERIENCE RETENTION **(SEER)**
3. FORMAL RESOURCES APPLICATION THROUGH PROGRAM MANAGEMENT TECHNOLOGY

VUGRAPH 4

management is resources development and resources application to achieve pre-determined objectives".

The 5th vugraph "Recognition of Need" quotes Mr. McNamara on disciplined decision-making to assure requirements optimization. Also it quotes Gen Schriever on discipline execution of the program management function after a project has been authorized. Quotations from Navy sources have been omitted because they are appropriate to the next meeting which deals with the system effectiveness activities of the Office of Naval Material.

SYSTEM EFFECTIVENESS CRITICAL ACTIVITIES

The 6th vugraph "Decision and Hardware SECA" stresses that the management system is concerned with the activities of people. It defines what is meant by a system effectiveness critical activity and illustrates the relationship of two types of activity to their products.

It should be noted that although hardware is the primary product, three types of data also are products.

The 7th vugraph "Design Critical Activities" illustrates four types of SECA and their relationship through design decisions. A management system does not seek to discipline the instantaneous working of a man's brain when he is using his judgment to make a decision. Rather it seeks to assure that appropriate and reliable data is generated and is used as a basis for decision making.

The 8th vugraph "Types of SECA" illustrates the first step in cataloging both decision or hardware or work SECA. A review and analysis of reliability specifications can lead to identification of reliability

WHY AN ASSURANCE MANAGEMENT SYSTEM

RECOGNITION OF NEED

REQUIREMENTS OPTIMIZATION

SYSTEM ANALYSIS ASSISTS THE DECISION MAKER BY FURNISHING HIM WITH QUANTITATIVE ESTIMATES OF THE EFFECTIVENESS AND COST OF EACH OF THE ALTERNATIVE COURSES THAT HE COULD CHOOSE. PERHAPS IT IS BEST DESCRIBED AS "QUANTITATIVE COMMON SENSE".

ROBERT S. MCNAMARA

PROGRAM OPTIMIZATION

THE MANAGEMENT CONTROL SYSTEM FORCES MANAGEMENT DISCIPLINE AND IT IS ONLY THROUGH DISCIPLINE THAT A GROUP OF PEOPLE, NO MATTER HOW WELL QUALIFIED INDIVIDUALLY, BECOME AN EFFECTIVE ORGANIZATION.

BERNARD A. SCHRIEVER

VUGRAPH 5

SYSTEM EFFECTIVENESS CRITICAL ACTIVITIES

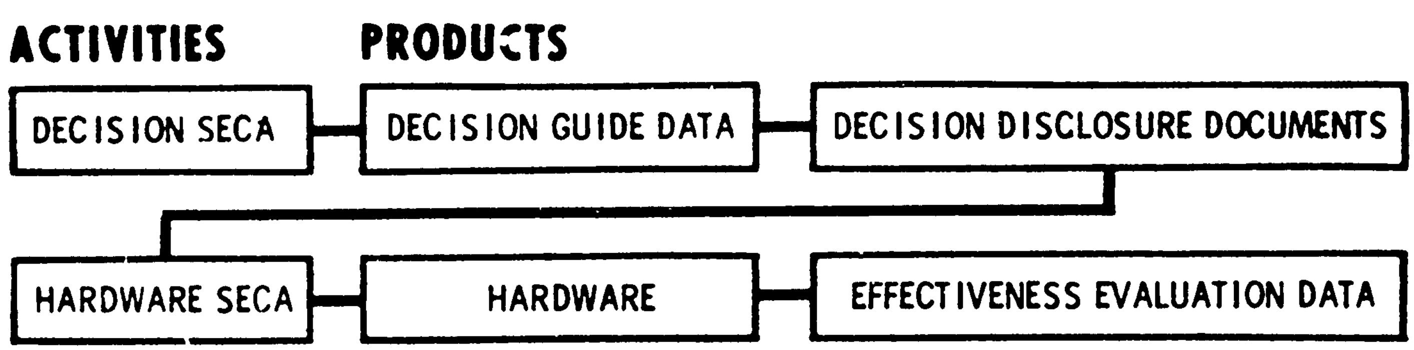
DECISION AND HARDWARE SECA

EFFECTIVE SYSTEMS ARE CREATED BY THE ACTIVITIES OF PEOPLE

THESE ACTIVITIES ARE OF TWO TYPES — DECISION CREATION.
— HARDWARE CREATION

DEFINITION OF SECA

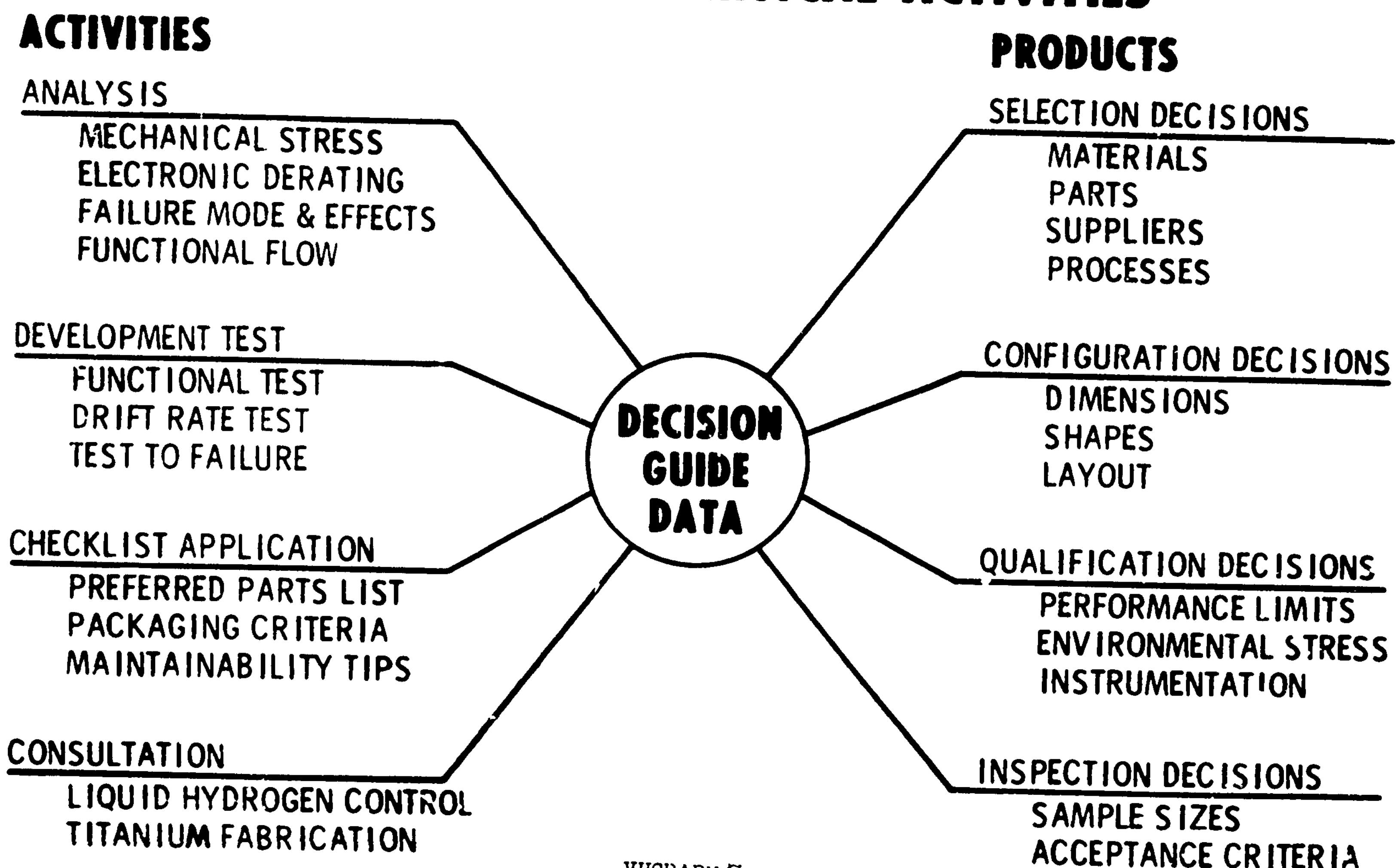
ANY DECISION OR HARDWARE CREATION ACTIVITY THAT MUST BE CONTROLLED BY FORMAL DISCIPLINE TO ASSURE SYSTEM EFFECTIVENESS IS CALLED A SYSTEM EFFECTIVENESS CRITICAL ACTIVITY (SECA)



VUGRAPH 6

SYSTEM EFFECTIVENESS CRITICAL ACTIVITIES

DESIGN DECISION CRITICAL ACTIVITIES



VUGRAPH 7

SYSTEM EFFECTIVENESS CRITICAL ACTIVITIES (SECA)

TYPES OF SECA

DECISION SECA	WORK SECA
ANALYSIS	PROCESSING
TEST	FABRICATION
CHECK LIST	ASSEMBLY
CONSULTANT	HANDLING

VUGRAPH 8

SECA. Similarly a review and analysis of maintainability specifications can lead to identifying activities that the writer considered to be critical to system effectiveness.

SYSTEM EFFECTIVENESS ASSURANCE MANAGEMENT SYSTEM

So far we have defined only creation activities. This means activities that actually create or build in system effectiveness or some worn characteristic such as reliability that contributes to system effectiveness. It is entirely practical to produce a product such as a lawnmower by nothing but creating activities. Yet we know that for military programs we do require and perform other activities such as qualification, testing and receiving inspection. These activities do not create but they help assure system effectiveness.

The Navy has recognized the importance of assurance activities in many ways. For example, years ago the then Chief of the Bureau of Naval Ordnance required the Commanding Officer of the Naval Ordnance Laboratory to establish and operate an evaluation for assurance function independent of the development or creation function. Why does he bother with these non-creative assurance activities?

The 9th vugraph "Purposes of Assurance" seeks to answer this question. Several types of assurance activity such as qualification testing are like a hurdle that the program manager, designer, or machinist must overcome. The knowledge that he must do so makes it more probable that he will do a thorough job of performing system effectiveness by creating activities. The importance of increasing confidence that effectiveness has been built into a system is well illustrated by the

SYSTEM EFFECTIVENESS ASSURANCE MANAGEMENT SYSTEM (SEAMS)

PURPOSES OF ASSURANCE ACTIVITIES

1. INCREASE THE PROBABILITY THAT A SECA WILL BE PERFORMED SUCCESSFULLY
2. INCREASE CONFIDENCE THAT IT HAS BEEN PERFORMED SUCCESSFULLY

IT DOES SO BY ASSURING THAT DECISIONS ARE MADE AND PHYSICAL WORK IS PERFORMED BY TRAINED AND MOTIVATED PEOPLE, AND IN ACCORDANCE WITH THE BEST AVAILABLE TECHNIQUES, AND BY DEMONSTRATING THAT PREDICTED VALUES OF QUALITY, RELIABILITY, MAINTAINABILITY, VALUE, SAFETY AND OPERABILITY HAVE BEEN ACHIEVED.

VUGRAPH 9

Apollo Man Space Program. Certainly the NASA official responsible for the decision to launch man into space must be able to assure the public that every possible means of checking that a safe, reliable system has been created is used.

The 10th vugraph "Relation of Assurance Activities to SECA" is the most vital of all.

The most familiar types of assurance are those applied after the product has been completed. They include, design reviews, qualification testing, and receiving inspection. But after the fact assurance is not enough. We must assure that resources are developed for each critical activity. This is done through the first three types of assurance. Then we must assure that for each project the critical activities are required, funded, and scheduled. This is done through program planning. Also we must assure that these critical activities are being performed well during the time they are being performed. This is done through important surveillance.

The six types of assurance together with the identification of critical activities constitute the system effectiveness assurance management system. The nature of this system may be illustrated many ways.

Vugraph 11 "Resources Development and Application" relates the system to the definition of management as resources, development and application to achieve pre-determined objectives.

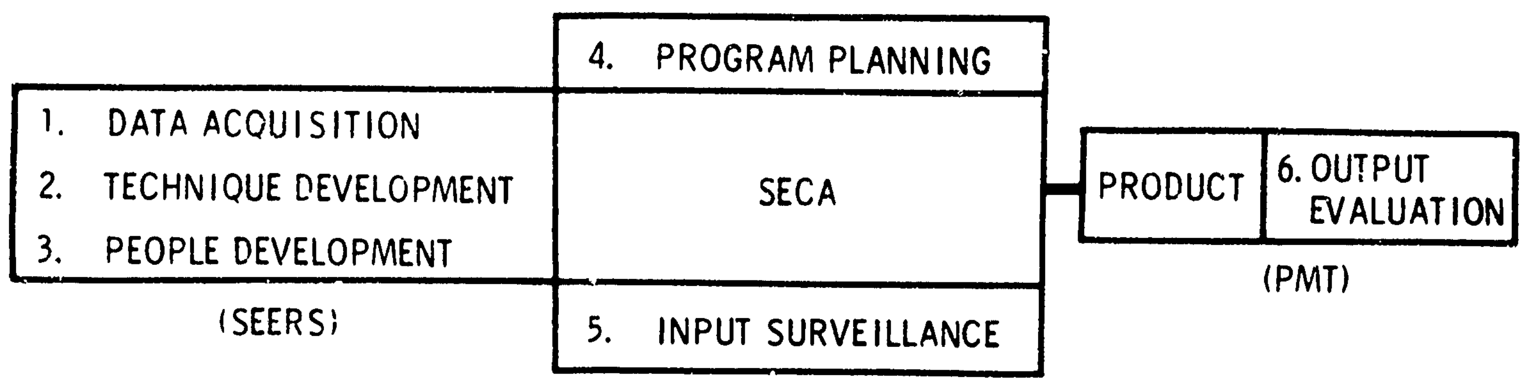
The 12th vugraph "Dynamic Closed Loop" illustrates that the system works continuously by feedback and integration.

The 13th vugraph "Data Acquisition Foundation" illustrates the

SYSTEM EFFECTIVENESS ASSURANCE MANAGEMENT SYSTEM (SEAMS)

RELATION OF ASSURANCE ACTIVITIES TO SECA

FOR EACH SECA SIX TYPES OF ASSURANCE ARE REQUIRED. FOUR ARE REQUIRED BEFORE IT IS PERFORMED, ONE DURING AND ONE AFTER.



DEFINITION OF SEAMS

ACTIONS TO PROVIDE THESE SIX TYPES OF ASSURANCE FOR EACH CRITICAL ACTIVITY CONSTITUTE A SYSTEM EFFECTIVENESS ASSURANCE MANAGEMENT SYSTEMS (SEAMS)

THE FIRST THREE CONSTITUTE AN SE EXPERIENCE RETENTION SYSTEM (SEERS).
THE SECOND THREE ARE PART OF PROGRAM MANAGEMENT TECHNOLOGY (PMT).

SYSTEM EFFECTIVENESS ASSURANCE MANAGEMENT SYSTEM (SEAMS)

RESOURCES DEVELOPMENT AND APPLICATION

RESOURCES DEVELOPMENT BY SE EXPERIENCE RETENTION (SEER)

1. DATA ACQUISITION
2. TECHNIQUE DEVELOPMENT
3. PEOPLE DEVELOPMENT

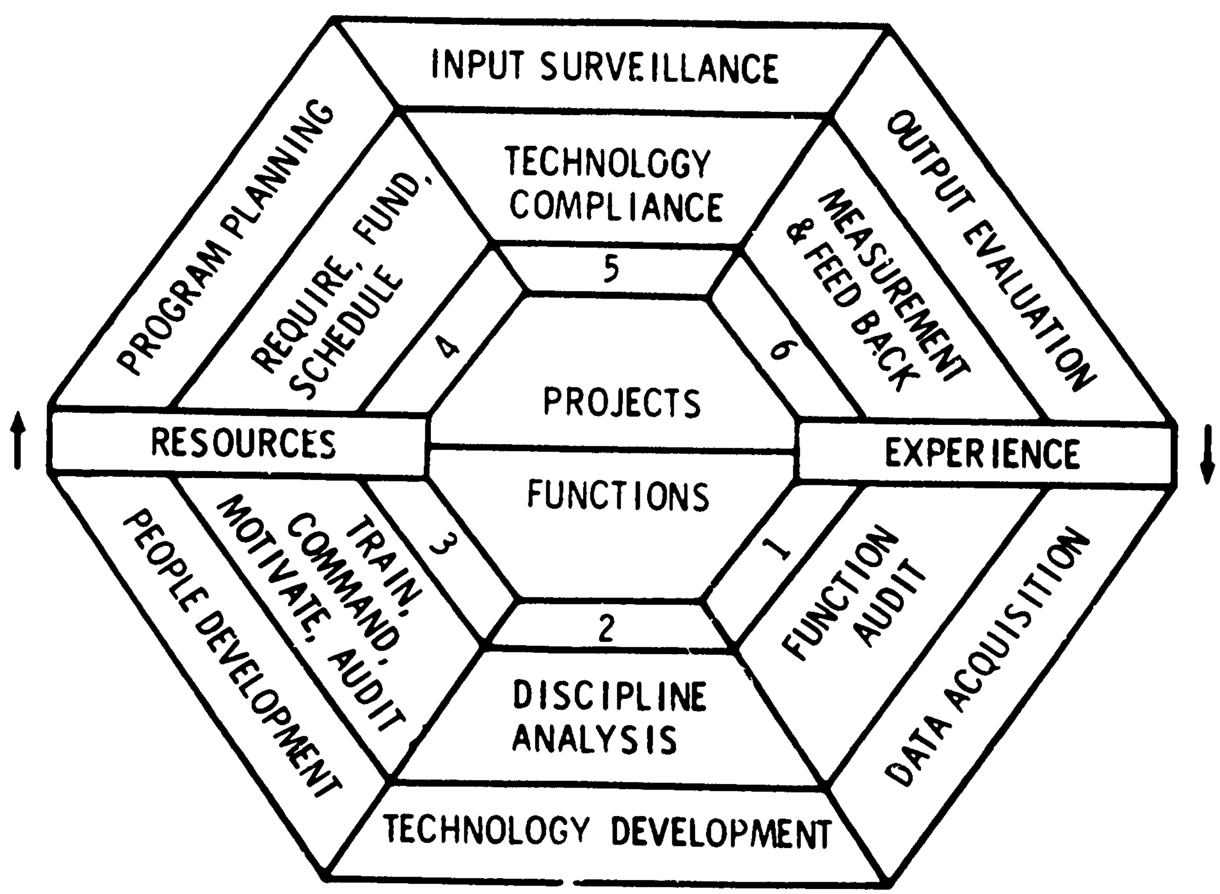
RESOURCES APPLICATION BY PROGRAM MANAGEMENT ASSURANCE TECHNOLOGY (PMAT)

4. PROGRAM PLANNING
5. INPUT SURVEILLANCE
6. OUTPUT EVALUATION

VUGRAPH 11

SYSTEM EFFECTIVENESS ASSURANCE MANAGEMENT SYSTEM

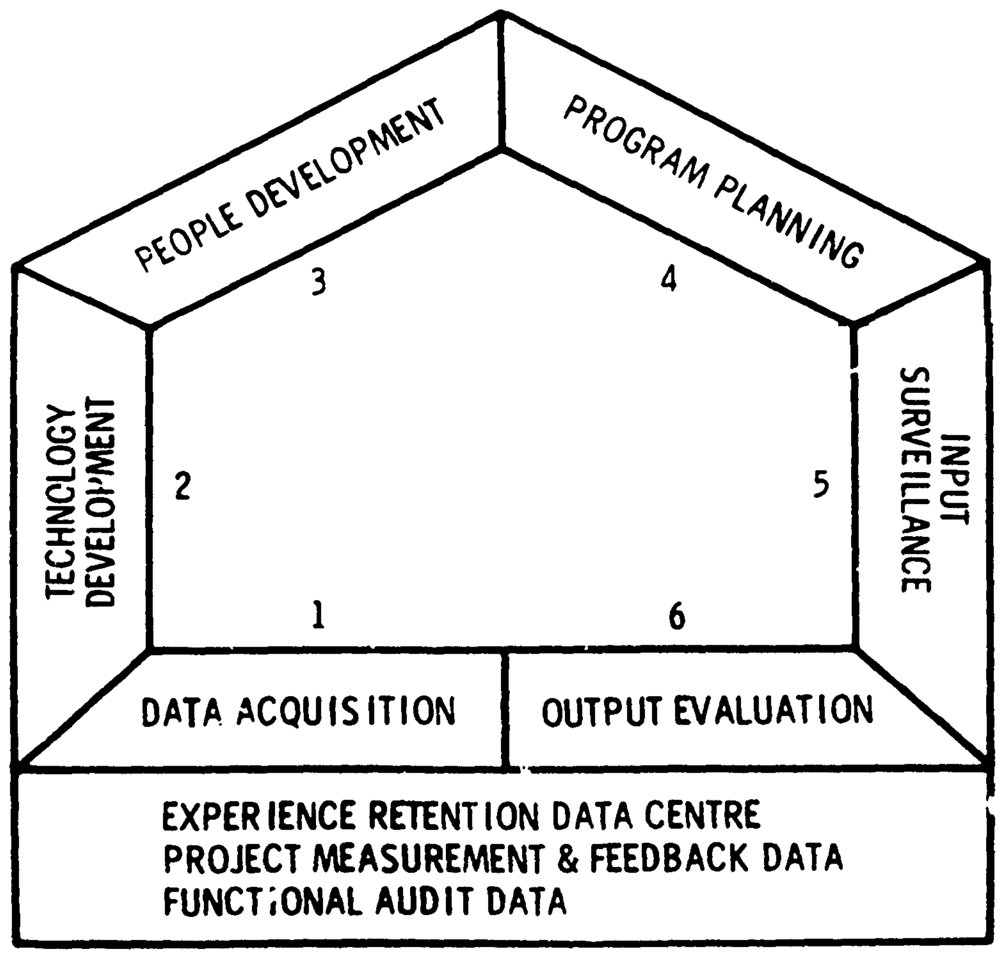
DYNAMIC CLOSED LOOP



VUGRAPH 1[illegible]

SYSTEM EFFECTIVENESS ASSURANCE MANAGEMENT SYSTEM

DATA ACQUISITION FOUNDATION



VUGRAPH 13

that the whole system is based on acquiring data from both a project data system and functional audit system.

The 14th vugraph "Audit Checklist" is important because it provides a basis for checking the status of current operations. For example it would permit ONM to check whether for a critical activity such as SOR writing data was being required on the successes and failures of present SORs. It would allow checking whether research money was being used to develop and document techniques for writing satisfactory SORs and it would permit checking whether the training and motivation of officer personnel included adequate instruction in the writing of SORs.

The 15th vugraph "Emphasis on People" merely reminds us that we are not dealing with an academic system but a down to earth practical method of achieving results through people. In fact people are the link between resources development by functional executives and resources application by program managers.

The 16th vugraph summarizes the segments of the assurance management system (also it stresses the acronyms seca, seer, pmt, and seams)

SE EXPERIENCE RETENTION

So much for the overall management system. The system takes on much more meaning when we get into the mechanics of resources development through experience retention and resources application through program management technology. We will discuss these topics briefly then get down to operating problems with a discussion of "contracting for system effectiveness".

SYSTEM EFFECTIVENESS ASSURANCE MANAGEMENT SYSTEM

AUDIT CHECKLIST

	RESOURCES DEVELOPMENT (Functional Executives)			RESOURCES APPLICATION (Operational Executives)		
CRITICAL ACTIVITIES	DATA ACQUISITION	TECHNOLOGY DEVELOPMENT	PEOPLE DEVELOPMENT	PROGRAM PLANNING	INPUT SURVEILLANCE	OUTPUT EVALUATION
eg. functional flow analysis						
eg. reliability prediction						
eg. trade studies						
eg. value engineering						

VUGRAPH 14

SYSTEM EFFECTIVENESS ASSURANCE MANAGEMENT SYSTEM

EMPHASIS ON PEOPLE

RESOURCE DEVELOPMENT

1. DATA ACQUISITION
2. TECHNOLOGY DEVELOPMENT
3. PEOPLE DEVELOPMENT

RESULT

QUALIFIED PEOPLE

RESOURCE APPLICATION

1. PROGRAM PLANNING
2. INPUT SURVEILLANCE
3. OUTPUT EVALUATION

RESULT

GOOD DECISIONS

GOOD WORK

FINAL RESULT - PREPLANNED LEVEL OF SYSTEM EFFECTIVENESS

VUGRAPH 15

SYSTEM EFFECTIVENESS ASSURANCE MANAGEMENT SYSTEM

SUMMARY OF SEAMS

ACTIVITY IDENTIFICATION

ASSURE IDENTIFICATION OF ALL SYSTEM EFFECTIVENESS CRITICAL ACTIVITIES ..... **SECA**

ASSURE IDENTIFICATION OF ALL SYSTEM EFFECTIVENESS ASSURANCE ACTIVITIES... **SEAA**

RESOURCES DEVELOPMENT

ASSURE RESOURCES DEVELOPMENT FOR EACH SECA AND EACH SEAA THROUGH SYSTEM EFFECTIVENESS EXPERIENCE RETENTION .... **SEER**

RESOURCES APPLICATION

ASSURE SYSTEM REQUIREMENTS OPTIMIZATION AND PROGRAM OPTIMIZATION RELATIVE TO OPERATIONAL EFFECTIVENESS, COST AND SCHEDULE THROUGH PROGRAM MANAGEMENT TECHNOLOGY .... **PMT**

VUGRAPH 16

To be replicable the development of system effectiveness resources must comply with the scientific method. The 17th vugraph deals with the scientific method. It shows that the 6 segments of our assurance management system correspondence quite precisely with the recognized four steps of the scientific method. It is important to note that the analysis step does not correspond with a physical description of a mode of failure. We as managers cannot prevent failures by changing the laws of physics but only by controlling the activities of people. Consequently, our analysis is concerned with how successes can be repeated or failures prevented from occuring through controlling the activities of people. Simarly our hypothesis step consists of predicting certain changes in the training,motivation, direction or audit of people will cause them to behave in a desired manner.

The 18th vugraph illustrates the principles of organization for experience retention. A functional executive for reliability or for system effectiveness does not need a line organization if he has the authority to make a closed loop program work. Irrespective of the organizational position of the people who perform each of the 6 segments of the closed loop system certain things must be provided for. Experience retention engineers preferably in a data central organization must generate (1) failure mode, probability and effects data, (2) a catalog of activities requiring formal discipline and (3) disciplinary requirements for each such activity. These requirements are passed on to the appropriate functional executive. He in turn absorbs the lessons learned into his management system in any way he chooses providing it will be effective.

RESOURCES DEVELOPMENT THROUGH SE EXPERIENCE RETENTION

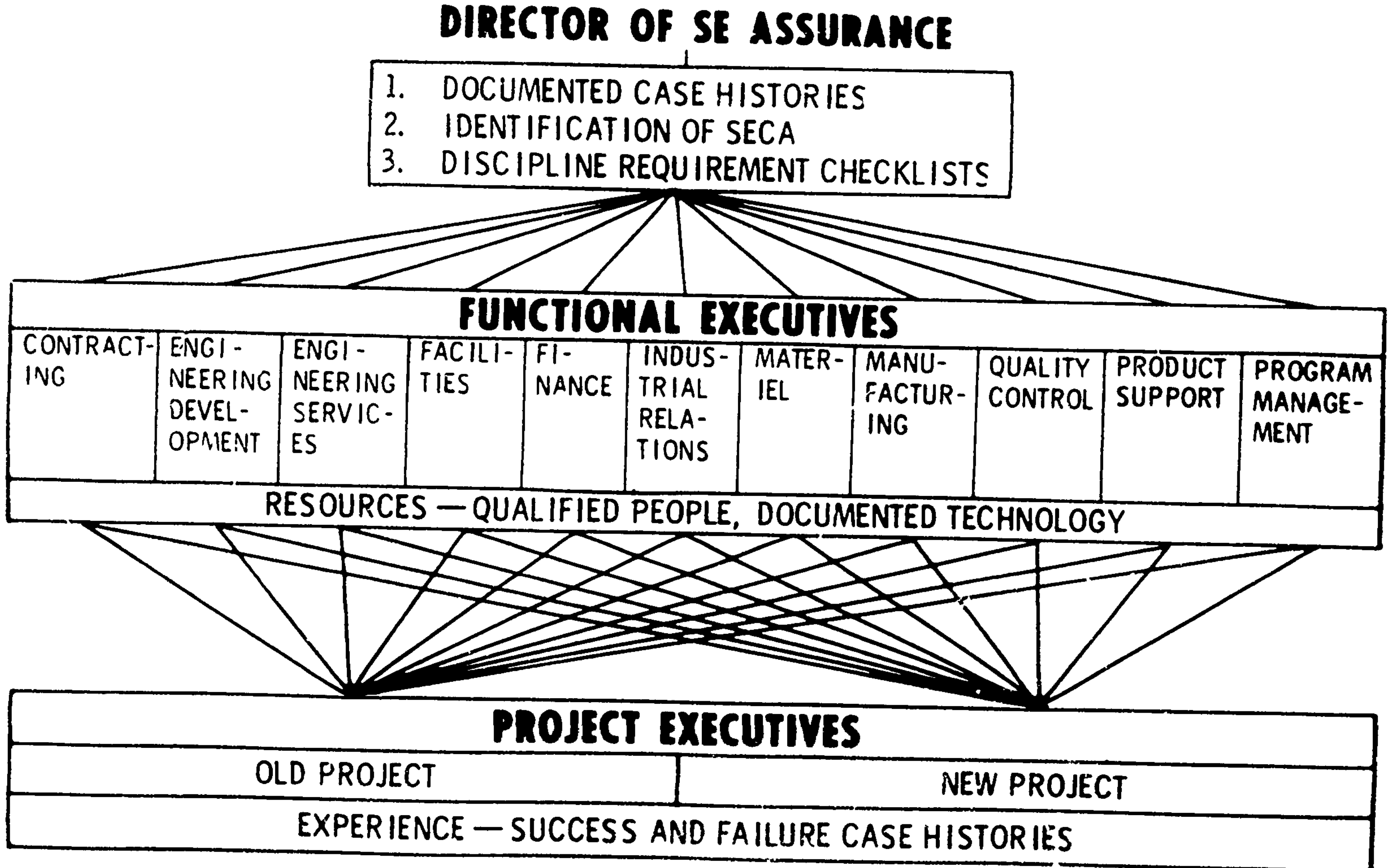
THE SCIENTIFIC METHOD

• OBSERVE	EQUIPMENT PROBLEMS AND SUCCESSES 1. DATA ACQUISITION
• ANALYZE	CONTROLLABLE ACTIVITIES OF PEOPLE 2. TECHNIQUE DEVELOPMENT
• HYPOTHESIZE	CHANGES IN TRAINING: MOTIVATION: DIRECTION: AUDIT WILL CONTROL ACTIVITIES 3. PEOPLE DEVELOPMENT
• TEST	APPLICATION OF IMPROVED RESOURCES
PLANNING	4. PROGRAM PLANNING
PLAN COMPLIANCE	5. INPUT SURVEILLANCE
RESULTS EVALUATION	6. OUTPUT EVALUATION

VUGRAPH 17

SYSTEM EFFECTIVENESS EXPERIENCE RETENTION

ORGANIZATION FOR EXPERIENCE RETENTION



VUGRAPH 18

Each functional executive produces resources in the form of documented disciplines and qualified people. The requirement for using these resources on each new project completes the closed loop system. The title of the 19th vugraph is "Discipline Requirements Yes - Procedures, No". Again we are facing the facts of human nature and seeking to answer two types of very real opposition to formalized experience retention.

The 20th vugraph "System Effectiveness Activities and Experience Retention" summarizes the responsibilities of functional executives.

PROGRAM MANAGEMENT TECHNOLOGY

The 21st vugraph "What is the System Effectiveness Activity" expresses the point of view of the program manager. From his point of view a SECA is so vital that it must be assured by planning surveillance and evaluation.

The 22nd vugraph brings out the importance of documentation to an assurance management system. Each of the three types of program management assurance involve documents. Program Planning involves documented plans. Surveillance is based on in process data. Evaluation includes evaluation of decision disclosure documents and the documentation of test and operational results.

For any assurance system to be accepted wholeheartedly and implemented people must have a positive attitude to the written word. A cavalier attitude that paper work may be justified because of the existence of a great deal of bad paper work is fatal to system effectiveness assurance.
The 23rd vugraph is a quotation from Gen Schriver. It forcibly expresses his opinion developed while responsible for the highly successful ICBM programs.

RESOURCES DEVELOPMENT THROUGH SEER

DISCIPLINE REQUIREMENTS YES — PROCEDURES NO

RESENTMENT OF STRAIT JACKETS

PROGRAM MANAGERS AND PROJECT ENGINEERS RESENT PROCEDURES.

THEY WILL ACCEPT PROCEDURAL GUIDES IF TERSE AND AUTHORITATIVE.

DISCIPLINE REQUIREMENT CHECKLISTS ARE TERSE AND AUTHORITATIVE.

MY PROJECT IS DIFFERENT

CREATIVE PEOPLE RESIST EVEN VALID LESSONS LEARNED FROM PRIOR EXPERIENCE.

THEY SAY MY PROJECT IS DIFFERENT.

EXPERIENCE MUST BE ANALYZED AND DISCIPLINE REQUIREMENTS EXPRESSED IN A WAY THAT MAKES THEM APPLICABLE TO NEW PROJECTS.

VUGRAPH 19

SYSTEM EFFECTIVENESS ACTIVITIES AND EXPERIENCE RETENTION

PROGRAM MANAGEMENT ACTION ON EACH SYSTEM EFFECTIVENESS ACTIVITY MUST BE SUPPORTED BY FUNCTIONAL MANAGEMENT ACTION. SUCH ACTION CONSISTS OF:

- DATA ACQUISITION

  ASSURE PROBLEM AND SUCCESS DATA ON CURRENT PROJECTS IS ACQUIRED AND RELATED TO EACH ACTIVITY.

- TECHNIQUE DEVELOPMENT

  ASSURE PROJECT AND RESEARCH EXPERIENCE IS FED BACK INTO TECHNOLOGY DOCUMENTS FOR EACH ACTIVITY.

- PEOPLE DEVELOPMENT

  ASSURE PEOPLE WHO CAN PERFORM EACH ACTIVITY ARE DEVELOPED BY TRAINING, MOTI VATION, COMMAND & AUDIT.

VUGRAPH 20

ASSURANCE MANAGEMENT

WHAT IS A SYSTEM EFFECTIVENESS ACTIVITY

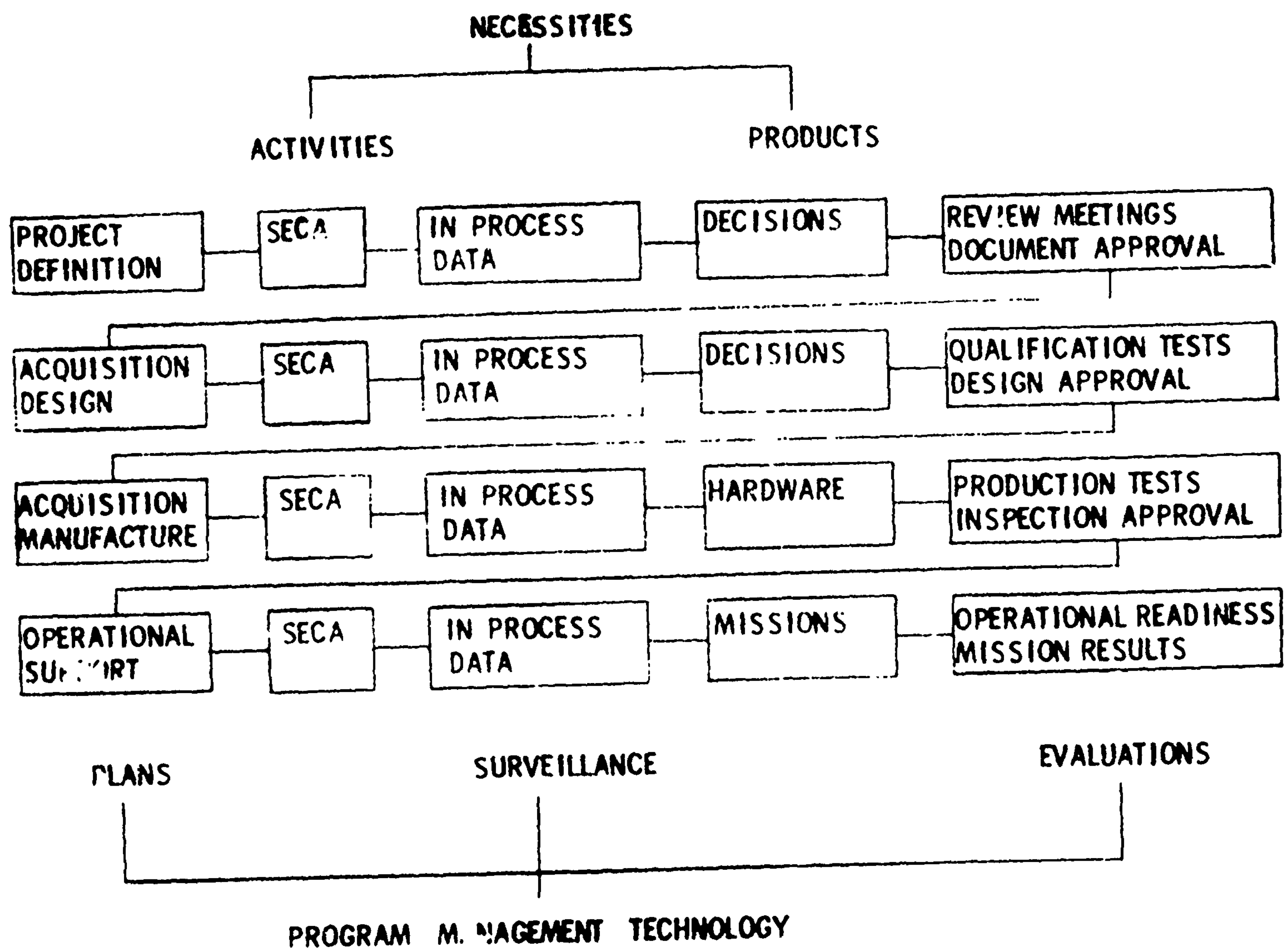
IT IS AN ACTIVITY SO VITAL TO ACHIEVING SYSTEM EFFECTIVENESS THAT ITS SATISFACTORY PERFORMANCE MUST BE ASSURED BY FORMAL PROGRAM MANAGEMENT ACTION. SUCH ACTION CONSISTS OF:

- PROGRAM PLANNING
  ASSURE ACTIVITY IS REQUIRED BY SPECIFICATIONS, 375 DOCUMENTS, OR WORK STATEMENTS.

- INPUT SURVEILLANCE
  ASSURE ACTIVITY IS BEING PERFORMED ON SCHEDULE BY QUALIFIED PEOPLE AND APPROVED PROCEDURES.

- OUTPUT EVALUATION
  ASSURE DECISION, HARDWARE, OR MISSION RESULTS DATA COMPLY WITH PREDICTED OR SPECIFIED CRITERIA.

VUGRAPH 21


NECESSITIES
ACTIVITIES
PRODUCTS
PROJECT DEFINITION
SECA
IN PROCESS DATA
DECISIONS
REVIEW MEETINGS DOCUMENT APPROVAL
ACQUISITION DESIGN
SECA
IN PROCESS DATA
DECISIONS
QUALIFICATION TESTS DESIGN APPROVAL
ACQUISITION MANUFACTURE
SECA
IN PROCESS DATA
HARDWARE
PRODUCTION TESTS INSPECTION APPROVAL
OPERATIONAL SUPPORT
SECA
IN PROCESS DATA
MISSIONS
OPERATIONAL READINESS MISSION RESULTS
PLANS
SURVEILLANCE
EVALUATIONS
PROGRAM MANAGEMENT TECHNOLOGY

VUGRAPH 22

PROGRAM MANAGEMENT TECHNOLOGY

JUSTIFICATION FOR DOCUMENTATION

"IF A MAN KNOWS WHERE HE IS GOING,
HOW HE IS GOING TO GET THERE, AND
WHERE HE IS NOW, HE CAN PUT IT ON
A PIECE OF PAPER."

GENERAL SCHRIEVER

VUGRAPH 23

..ie 24th vugraph illustrates the tough action that is being taken by the Air Force to insist on discipline program management by their contractors.

The 25th vugraph illustrates the action being taken by the Army Material Command to assure discipline decision making in their program management.

The 26th vugraph quotes from the DOD news release when directive 3200.9 was issued on March 4, 1964. It illustrates DOD in requirements on disciplined program management action at the beginning of each program.

Again we have avoided quotations from Navy sources because this is part of the subject of the next seminar.

OUTPUT CONTRACTING FOR SYSTEMS EFFECTIVENESS

The traditional way of doing business may be described by the term output contracting. This means that the relationship between the buyer and the seller is based exclusively on requirements and tests of the final product.

This is the third record requirements for and test of the final product. Vugraph 27 "Necessary Conditions", summarize output contracting.

Even when the relationship between the buyer and seller is based exclusively on output requirements it is still necessary to optimize these requirements through systems analysis. Also the overall system requirement must be converted into contributing characteristic requirements. These characteristics have to be things that can be required and specified at the appropriate level of contracting including pur-

PROGRAM MANAGEMENT TECHNOLOGY

AIR FORCE ACTION

"AFSC IS FINISHING A SERIES OF INDUSTRY WIDE DIRECTIVES WHICH APPLY TO ALL NEW SYSTEMS. SOME ALERT CONTRACTORS ARE ALREADY CHANGING INTERNAL STANDARD PROCEDURES. THOSE THAT ARE SLOW ARE GOING TO BE SURPRISED IN A COMPETITIVE ENVIRONMENT."

COLONEL BELLIS

VUGRAPH 24

PROGRAM MANAGEMANT TECHNOLOGY

ARMY ACTION

AMCR 11-16 ESTABLISHES THE BASIC POLICIES, CONCEPTS, OBJECTIVES, PHILOSOPHY, AND REQUIREMENTS OF PROJECT MANAGEMENT WITHIN THE ARMY MATERIEL COMMAND. THE TOTAL DECISION MAKING PROCESS IS BASED UPON THE DIRECT RELATIONSHIP OF TIME, COST, AND TECHNICAL PERFORMANCE.

GENERAL BESSON

VUGRAPH 25

ASSURANCE MANAGEMENT

DOD NEWS RELEASE - MARCH 4, 1964

PDP INVOLVES SIGNIFICANT CHANGES AND WILL HAVE A LARGE IMPACT ON DEFENSE CONTRACTORS.

PDP IS A PERIOD OF TIME SET ASIDE FOR PRECISE PLANNING OF ENGINEERING, MANAGEMENT, SCHEDULES AND COST FACTORS, PRIOR TO COMMITMENT TO A FULL-SCALE DEVELOPMENT PROJECT.

PDP WILL BE APPLIED TO ALL PROJECTS WHOSE ESTIMATED DEVELOPMENT COSTS AMOUNT TO $25 MILLION OR WHOSE ESTIMATED PRODUCTION COSTS AMOUNT TO $100 MILLION.

MAJOR BENEFITS ARE: REDUCTION OF TECHNICAL CHANGES, DECREASED TOTAL COST IMPROVED OPERATIONAL EFFECTIVENESS, EARLY CANCELLATION.

OUTPUT CONTRACTING

NECESSARY CONDITIONS

FOR OUTPUT CONTRACTING TO BE SATISFACTORY TO THE BUYER THESE CONDITIONS MUST EXIST.

1. THE BUYER CAN SPECIFY NUMERICALLY EVERY REQUIREMENT FOR THE PRODUCT, INCLUDING RELIABILITY AND MAINTAINABILITY.
2. THE BUYER AND SELLER CAN AGREE ON A FUNDED DEMONSTRATION TEST THAT WILL PROVE THAT ALL NUMERICAL REQUIREMENTS HAVE BEEN MET.
3. THE BUYER CAN TOLERATE THE SCHEDULE DELAY AND EXTRA COST THAT WILL RESULT IF THE SELLER FAILS TO PASS A SPECIFIED DEMONSTRATION TEST.

DEFINITION: OUTPUT CONTRACTING IS A BUYER-SELLER RELATIONSHIP IN WHICH THE SELLER'S ONLY TECHNICAL COMMITMENT IS TO PRODUCE A PRODUCT THAT PASSES QUALIFICATION TEST AND RECEIVING INSPECTION.

VUGRAPH 27

chase orders for parts. Vugraph 28 "Requirements Optimization" illustrates thes^ points.

Vugraph 29 "Derivation of Requirement" illustrates three steps from overall operational effectiveness concepts to quantitative requirements suitable for inclusion in contracts and purchase orders. The technology for making trade-offs that result in contractor requirements is a very large subject which we will not be able to discuss today. The important point is that these quantitative analyses and trade-offs are essential to supporting output contracting for Systems Effectiveness.

INPUT CONTRACTING FOR SYSTEMS EFFECTIVENESS

When a buyer cannot afford the risks associated with output contracting he must take action to assure that system effectiveness is built in from the beginning of the program. We call such action input contract.

There have been many attempts to require input contracting to assure a single characteristic such as reliability or maintainability. Vugraph 30 "Specifications That Require Discipline Procedures" illustrates the attempts to establish input con' :ting through specifications.

There has been a great deal lustry persistence to specifications that seem to direct managemen. practices in the name of a single cult. It is being realized slowly that government-industry cooperation in formalized overall program management practices can eliminate the need for the management aspects of a large number of specifications such as MIL-Q 9858A.

Even when industries has accepted principle of input contracting

OUTPUT CONTRACTING FOR SYSTEM EFFECTIVENESS

REQUIREMENTS OPTIMIZATION

SYSTEM ANALYSIS

PAST CONTRACT REQUIREMENTS WERE LIMITED TO PERFORMANCE CAPABILITY, NOW PREDICTION & TRADE-OFF TECHNIQUES PERMIT TOTAL REQUIREMENTS OPTIMIZATION

CONTRIBUTING CHARACTERISTICS

SPECIFICATION REQUIREMENTS ARE EXPRESSED AS NUMERICAL VALUES FOR ALL CHARACTERISTICS THAT CONTRIBUTE TO SYSTEM EFFECTIVENESS AND THAT CAN BE DEFINED AND MEASURED. THESE CHARACTERISTICS INCLUDE:

QUALITY — ABILITY TO PASS INSPECTION
RELIABILITY — FREEDOM FROM FAILURE AFTER INSPECTION
MAINTAINABILITY — EASE OF FAILURE PREVENTION & REPAIR
OPERABILITY — EASE OF OPERATION BY HUMAN SUBSYSTEM
VALUE — MONEY COST OF FUNCTION ACCOMPLISHMENT
SAFETY — FREEDOM FROM LIFE & PROPERTY LOSS

VUGRAPH 28

OUTPUT CONTRACTING FOR SYSTEM EFFECTIVENESS

DERIVATION OF REQUIREMENTS

STEP 1 OPERATIONAL EFFECTIVENESS

OPERATIONAL EFFECTIVENESS IS THE PROBABILITY THAT A SYSTEM CAN SUCCESSFULLY MEET AN OPERATIONAL DEMAND, WITHIN A GIVEN TIME, WHEN OPERATED UNDER SPECIFIED CONDITIONS (WSEIAC)

STEP 2 OE = CAPABILITY X AVAILABILITY X MISSION RELIABILITY

AVAILABILITY IS A FUNCTION OF PRE-MISSION RELIABILITY & MAINTAINABILITY
MISSION RELIABILITY INCLUDES OPERABILITY AND SAFETY AND SO ON.

STEP 3 COST AND SCHEDULE

OE CHARACTERISTICS MUST BE RELATED TO & TRADED AGAINST COST & SCHEDULE

VUGRAPH 29

INPUT CONTRACTING

SPECIFICATIONS THAT REQUIRE DISCIPLINED PROCEDURES

D.O.D.	
MIL-O-9858A	QUALITY PROGRAM REQUIREMENTS
MIL-R-27542A	RELIABILITY PROGRAM FOR SYSTEMS, SUBSYSTEMS & EQUIPMENT
MIL-M-26512C	MAINTAINABILITY PROGRAM REQUIREMENTS FOR AEROSPACE SYSTEMS & EQUIPMENT
MIL-H-27894	HUMAN ENGINEERING REQUIREMENTS FOR AEROSPACE SYSTEMS & EQUIPMENT
MIL-S-38130	SAFETY ENGINEERING OF SYSTEMS AND ASSOCIATED SUB-SYSTEMS, AND EQUIPMENT, GENERAL REQUIREMENTS FOR
NASA	
NPC 200-1	QUALITY ASSURANCE PROVISIONS FOR INSPECTION AGENCIES
NPC 200-2	QUALITY PROGRAM PROVISIONS FOR SPACE SYSTEMS CONTRACTORS
NPC 200-3	INSPECTION SYSTEM PROVISIONS FOR SUPPLIERS OF SPACE MATERIALS, PARTS, COMPONENTS, AND SERVICES
NPC 250-1	RELIABILITY PROGRAM PROVISIONS FOR SPACE SYSTEM CONTRACTORS

VUGRAPH 30

the objective is still to limit the amount of constraint to the minimum. Vugraph 31 "Industry Objectives" clarifies the relation of this attitude to Systems Effectiveness critical activities.

Vugraph 32 "Steps in Constraint of Contractors" illustrates that industry wishes to use that method of contracting which requires the minimum degree of constraint for a particular procurement. Whenever possible both buyer and seller still prefer to do business on the basis of pure output contract. At the other extreme large new systems that involve a group of associated contractors and many innovations in technology require the illustrated additional disciplines in program planning assurance, inputs surveillance assurance, and output evaluation assurance.

From the industry point of view a formal system effectiveness assurance management system makes sense if, 1) All the critical activities that are called out in the contract are well defined and have been proved to be critical by previous experience. 2) The customer encourages and rewards resourcefulness of development by industry for each critical activity. 3) The customer has the qualified people and proven methods necessary to evaluate industry's effort in applying resources to each critical activity.

Unfortunately, a great deal remains to be done by both government and industry before these conditions can be considered satisfactorily fulfilled. What has been done by specifications leaves much to be desired. For example, the truly critical activities are not well defined nor is their criticality established by straightforward government-industry evaluation and agreement.

INPUT CONTRACTING

INDUSTRY OBJECTIVES

GENERAL

MINIMUM CONSTRAINT OF CONTRACTORS BY CUSTOMERS

SPECIFIC

(1) MINIMUM NUMBER OF ACTIVITIES DESIGNATED AS SECA

(2) MINIMUM DEGREE OF CONSTRAINT FOR EACH SECA

VUGRAPH 31

INPUT CONTRACTING

STEPS IN CONSTRAINT OF CONTRACTORS

1. **PURE OUTPUT CONTRACTING**

   QUALIFICATION TEST AND RECEIVING INSPECTION ONLY

2. **MODIFIED OUTPUT CONTRACTING**

   ADD DESIGN REVIEWS

3. **NEGOTIATED WORK STATEMENT**

   ADD REQUIREMENTS FOR A LIST OF SECA

4. **PROGRAM PLAN ASSURANCE**

   ADD PROGRAM PLANS TO REQUIRE, SCHEDULE AND FUND CULT: SECA

5. **INPUT SURVEILLANCE ASSURANCE**

   ADD IN-PROCESS DATA SUBMITTAL REQUIREMENTS FOR EACH SECA

6. **OUTPUT EVALUATION ASSURANCE**

   ADD CONFIGURATION MANAGEMENT FOR ALL DECISION DISCLOSURE DOCUMENTS

VUGRAPH 32

The time has come for mutual industry-government action in describing and implementing a totally integrated, fully justified system effectiveness assurance management system. Such a system will help immeasurably not only to get effective systems for the Navy, but to assure harmonious relations between the Navy and Navy contractors. Mutual confidence and respect is an important by-product that should be achieved by any system effectiveness assurance management system.

SYSTEMS EFFECTIVENESS

A TOOL FOR APPRAISAL

To be Presented at

WESTERN STATES NAVY R&D CLINIC
MONTANA STATE COLLEGE
BOSEMAN, MONTANA

22 July 1964

Cdr Keith N. Sargent, USN
Head, Systems Effectiveness Branch
Office of Naval Material

Dr. Trumbull, ladies and gentlemen

The term "System Effectiveness" in a generic sense is usually understood to mean the ability of a system to perform according to its purpose. Since this is a qualitative characteristic, it is difficult at the outset to envision it as a tool. However, if we were able to quantize the various attributes of a system which go to make up this quality we could establish measures of the quality. Having established measures, these can be compared in a number of ways: predicted vs achieved, achieved at one point in time vs that of a later point in time, predicted or achieved in one system vs predicted or achieved of another, one combination of attributes vs a differing combination of attributes, among others. These comparisions are the vehicles for appraisals which become the tools of management in making the decisions which determine the future course of our efforts.

This is a nice rationale but it is conditional upon the big "if" at the outset. -- If we are able to quantize. Actually I am persuaded that "if" may not be the right word. Rather, I would suggest that we should use the word "when". This stems from the conviction that the condition is not a matter of whether or not quantizing is possible but rather one of whether or not we are capable of learning how to quantize.

In support of this contention, let us examine one proposed approach to quantifying systems effectiveness. This approach was

presented by the Cost Effectiveness Panel at the recent Aerospace Reliability and Maintainability Symposium in Washington and is published in its Proceedings.

Let me first present the generalized formula and then pursue its derivation. Actually two formulae were presented.

$$(1) \quad E_c = \frac{PAU}{C_a + C_u} \qquad\qquad E_c = W \frac{PAU}{C_a + C_u}$$

Although there is a significant difference between the two in that the W is a constant representing the military worth of the mission of the system, I shall for the moment use the first of the two formulae. The term E_c represents Cost Effectiveness. I would remind you that we are not discussing Cost Effectiveness per se, but rather Systems Effectiveness. Nevertheless Systems Effectiveness taken out of the context of Cost Effectiveness is a sterile academic exercise productive of little but to impress our fellows with our erudition. Since we are pursuing a useable tool, I have elected to keep Systems Effectiveness in a useful context ie: within Cost Effectiveness.

Looking to the denominator of the fraction in (1) we find the terms C_a & C_u. These are Cost of Acquisition and Cost of Utilization respectively. These are the terms which convert the expression to a statement of Cost Effectiveness. These are the determinants of the cost context. I shall not pursue their derivation in this particular discourse.

There remain three terms, P, A & U. These provide the substance of our systems effectiveness model, where

(2) $E = PAU$

The term P - Performance is a numerical index expressing system capability, assuming a hypothetical 100% availability, reliability and utilization of performance capability in actual operation. This index can be expressed in any suitable terms dependent upon the nature of the mission. For instance in a satellite system it could be in rated pounds of payload into orbit per successful vehicle. In a missile system it could represent target square miles killed per successful launch. In effect it is the mission determinant parameter. It matters little what the index selected may be, provided that in the use of the formula, the index used is the determinant parameter for the systems being appraised through comparison ie: in the determination of P_α, P_β, P_γ etc. where these values obtain for systems α, β, γ respectively.

The term U, Utilization is the fraction of the performance capability actually utilized due to the specific application and the environment encountered. In effect it expresses all of the effectiveness degradation due to causes external to the system itself. I would point out that this is a term largely out of the control of the designer, and one which in the final analysis can only be established ex post facto. Nevertheless it is a function which can vary as a result of inherent design limitations. Such factors as consideration of operational, physical and in some cases political environmental

factors operate on this function. These considerations are under the designer's control albeit subject to the adequacy of communication of these environmental parameters by the user. Because of this designer control, the value U must be considered if only with a probabilistic estimated value. However, the analyst MUST exercise great objectivity and care to insure that a biasing effect is not introduced through failure to develop U_α, U_β & U_γ on equitable bases.

The central term A is the period, or fraction of time, that the system is ready and capable of fully performing its mission. It makes little difference whether A is expressed as a period or a fraction as long as the mode of expression is consistent throughout a given appraisal or analysis. In those systems having a finite mission time, it is convenient to use the fractional expression.

Conventionally A is expressed as

$$(3) \quad A = \frac{MTBF}{MTBF + MTTR}.$$

I would point out that this condition exists only at the point $t = 0$. It is comforting to know that a system is ready to go. But in a military system, the payoff is in successful completion of the mission. $t = 0$ or t_o is just the beginning. We must have an expression which will permit us to predict A at the point of t_ω, the completion of the mission.

To the end of realizing such an expression of A, I'd like to state some defintions of terms followed by the derivation of an expression of A which appears to be useful. (See Fig #1)

(T) Stress Time is the time during which stresses occur that can induce failure. Such stresses are normally present during some fraction or all of "operational" time, and also usually during standby and maintenance time. This chart illustrates the major elements of stress time, but as a ratio to the number of failures:

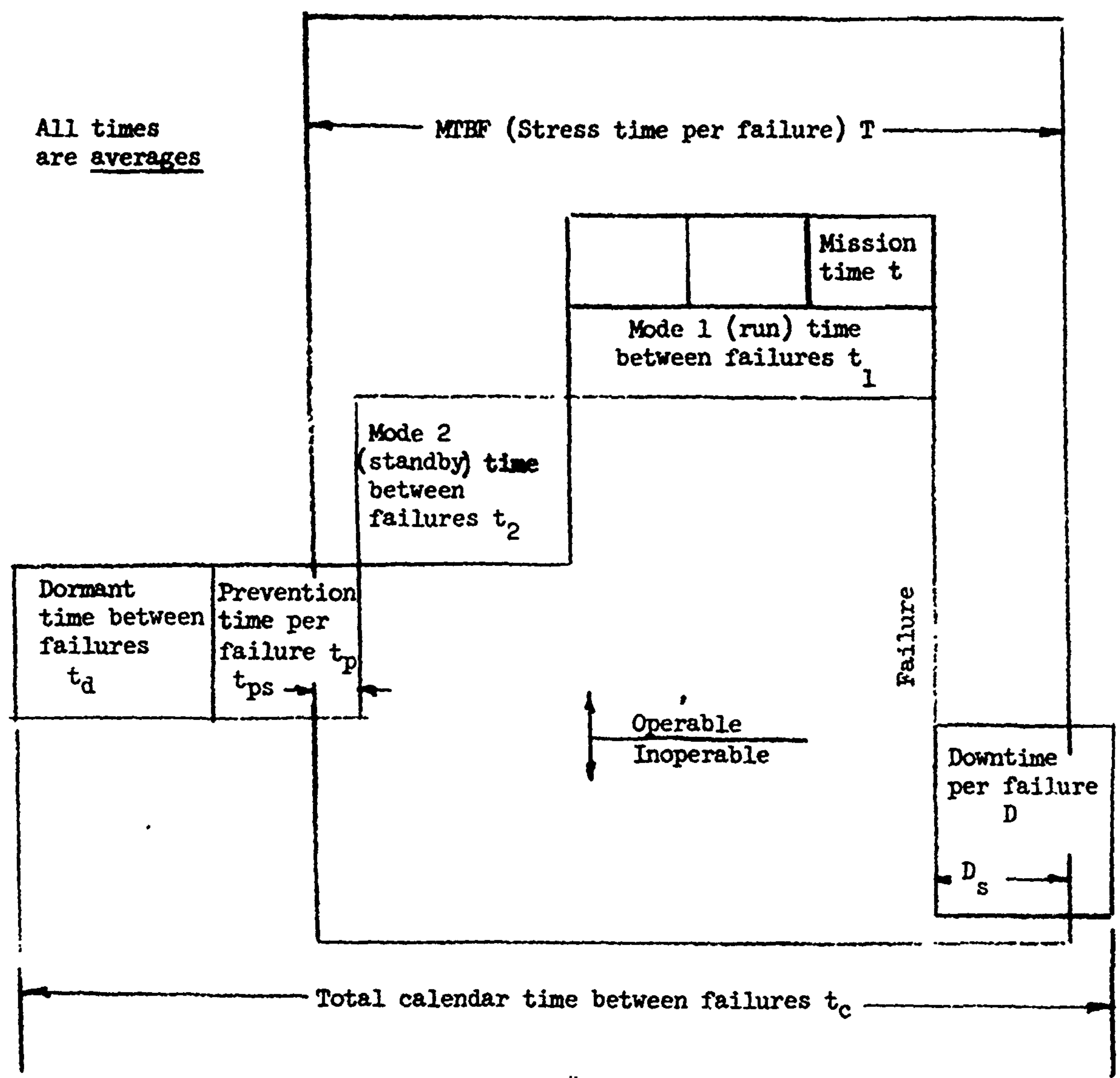


Fig #1

(t) Mission Time is the time during which the system is committed to completion of one operational mission.

Mean Time Between Failures is the average stress time between failures, assuming no redundant compensation unless specified. It is the primary index of design reliability, and equal to the reciprocal of Failure Rate λ.

(R) Reliability is the fraction of successful mission starts which have been or will be subsequently completed without failure. Predicted Reliability R_p is then the probability that, successfully started, the system will complete operation for a specified time without failure, or

(4) Predicted Reliability $R_p = e^{-t/T} \approx 1 - t/T$ when $t \ll T$

Downtime Per Failure is the mean time for restoration (MTTR) to reliable operation, including detection, diagnosis, logistic procurement, replacement or repair, checkout, and (for memories) reload. "Repair" time is but part of this.

(M) Maintainability is the quantitative index of ease with which restoration is accomplished. Typical measures are (a) the number of failures restored per hour of downtime ($M = 1/D$), (b) the fraction of attempts wherein restoration is completed in a specified time. and (c) operational time per dollar cost of preventive and corrective maintenance.

(A_d) Demand Availability is the fraction of stress time that upon demand the system can be operated without failure, assuming that any preventive maintenance can be interrupted. It is equal to the probability that the system can start successfully and complete

the required mission time without failure, at any random demand time. Since the mission will fail if it starts any later, on the average, than time t before failure, or within downtime D following failure,

$$(5) \quad A_d = 1 - \frac{t+D}{T-t_{ps} + D-D_s}$$

where D_s is that portion of downtime D during which stress occurs, and t_{ps} is that portion of preventive maintenance time t_p during which stress occurs.

If there is stress during substantially all of downtime, which is usually the case, $D_s = D$. Then if there is no stress during preventive maintenance, $t_{ps} = 0$ and we have

$$(6) \quad A_d \approx 1 - \frac{t + D}{T}$$

If there is no stress during downtime, which is rare, $D_s = 0$. Then if there is still no preventive stress, $t_{ps} = 0$ and :

$$(7) \quad A_d \approx 1 - \frac{t + D}{T + D} = \frac{T - t}{T + D}$$

If we ignore the reliability effect of incomplete missions on Availability, t = 0. Then we have the familiar form:

$$(8) \quad A_d \approx \frac{T}{T + D} = \frac{MTBF}{MTBF + MTTR}$$

(A_c) Continuous Availability is the fraction of stress time that the system can be operated without failure, allowing for both downtime and preventive maintenance.

$$(9) \quad A = 1 - \frac{t + D + t_p}{T-t_{ps} + D-D_s} = 1 - \frac{t + D + t_p}{T}$$

(U) Utilization is the fraction of performance capability actually utilized due to the specific application and environment

encountered. It expresses all effectiveness degradation due to causes external to the system itself.

Example: 63% Tactical Effectiveness due to narrow application (70%) and adverse environment (90%)

It is this Continuous Availability expression which provides a value for A which will permit us to predict cut to the point in real time t_w. Thus our expression can be written

$$(10) \quad E = P \left(1 - \frac{t + D}{T}\right) U$$

At this juncture, I would like to acknowledge my indebtedness to the Messrs. E. S. Winlund and C. S. Thomas for their contributions to this derivation.

There is one remaining term in our expression, E. I have previously indentified this term as Effectiveness or more precisely Systems Effectiveness. Further, I expressed it as a generic term. To avoid misunderstanding I would provide a more exact definition of the term in the context which it is used here. The conceptual definition is the probability that the system can successfully meet an operational demand throughout a given time period when operated under specified conditions. I'm indebted to WSEIAC Group I (AFSC's Weapons System Effectiveness Industrial Advisory Committee) for this phrasing. The mathematical definition must be the <u>index</u> of the conceptual definition since the analyst may elect to use a non-fractional expression of the term U and, the term P is usually neither fractional nor the percentile expression normally associated with probabilities.

Having arrived at a generalized expression of Systems Effectiveness, let us look at the utility of the tool. A prudent mechanic knows not

only the purpose of his tool but also the limitations of its use. Further, if it is a cutting tool, he is careful to dress its edge exactly to the job at hand taking into account the material to be worked and the character of the shape to be produced. As homely as this analogy may be, it is singularly appropriate for our purposes.

Our tool is a generalized one and like a cutting tool blank is useful only if the proper edge is formed. This must be accomplished by the user and can only be as effective as the capability of the user to provide the proper edge. This is accomplished in our general expression through selection of the measures selected for the terms P and U. This is the critical criterion for successful use of the expression.

Continuing the analogy, the user must ensure that successive use of the tool involves like material. The measures selected for the terms P & U must be appropriate to the systems being analyzed. This is apparent to the analyst. But, this is not always so readily apparent to successive review levels. There is an inherent danger in using indices in that these may be received on a "numbers are numbers" basis without realizing that the numbers are to differing bases. To avoid this, it becomes mandatory that the users of this generalized expression explicitly include the index base when citing numeric values of E.

A second problem in the use of the expression evolves from the fact that all three terms are probabalistic. This makes the term E probabalistic as it indeed is by definition. It therefore becomes imperative that the associated confidence factor be expressed when

numeric values of E are cited. I use the term imperative because this is an oft overlooked factor. While common sense may reject the results, any statiscal analyst can demonstrate mathematically any achieved probability desired, from any set of data, if he is at liberty to adjust the confidence factor. This factor, sometimes referred to as the degree of goodness, must be expressed if valid appraisals are to be made. This is particularly so if these appraisals are conducted before there is a significant number of experience samples. I would point out here that in many military systems, statistically significant experience samples are never achieved except as post mortems. It is a fact of life that in some there may be no one to conduct such a post mortem.

I stated earlier that Systems Effectiveness taken out of the context of Cost Effectiveness was a sterile academic exercise. Permit me to set up a hypothetical situation to illustrate the point.

$$E = PAU$$

$$P_\alpha = 875;\ A_\alpha = .65;\ U_\alpha = .7$$

$$E_\alpha = 875 \cdot .65 \cdot .7 = 398.125$$

$$P_\beta = 800;\ A_\beta = .80;\ U_\beta = .85$$

$$E_\beta = 800 \cdot .80 \cdot .85 = 544.0$$

$$P_\gamma = 875;\ A_\gamma = .80;\ U_\gamma = .85$$

$$E_\gamma = 875 \cdot .80 \cdot .85 = 612.0$$

Fig #2

Here we have three systems with a single functioned mission. That is to say that their missions are identical and all differences are a direct function of the systems themselves.

System α is determined to have a performance index value of $P_\alpha = 875$, a calculated value of $A_\alpha = .65$ and an estimated value of $U_\alpha = .7$. The value of E_α is 398.125.

System β analysis indicates values of $P_\beta = 800$, $A_\beta = .80$ and $U_\beta = .85$. Thus $E_\beta = 544.0$

System γ is determined to have values of $P_\gamma = 875$, $A_\gamma = .80$ and $U_\gamma = .85$. The resultant E_γ is 612.0.

Let us assume that all the calculations are to a common base where total mission capability is 1000. For the moment, let us also assume that the confidence factors in all three calculations are the unlikely situation of being equivalent.

It would appear that system α has a capability to out perform system β. In the absence of system γ, and without a thorough analysis, many would elect it for this reason. However, upon analysis it is clear that system β is superior on a systems effectiveness basis since its E is substantially better than system α.

But we do have system γ. It combines the performance capability of α with the availability and utilization characteristics of β. From a systems effectiveness point of view its E of 612.0 is clearly above either β's 544.0 or α's 398.125. In logic, since it combines the best of both the other systems, as well as in mathematics, the decision is clear. Support system γ, on the basis of systems effectiveness.

But - let's not overlook the old saw that you get nothing for nothing. Increased performance and increased availability are not free.

$$E_c = \frac{PAU}{C_a + C_u}$$

$$E_{c\beta} = \frac{544}{1.2 + 3.0} = 134.29$$

$$E_{c\alpha} = \frac{398.125}{1.4 + 5.0} = 62.2$$

$$E_{c\gamma} = \frac{612}{6.0 + 8.0} = 43.7$$

$$E_{c2\alpha} = \frac{398.125}{12.8} = 31.1$$

Fig #3

The acquisition cost per system β, which employs state-of-the-art circuitry, is \$1.2 $\overline{M}$. Because the majority of its components are proven and operator and maintenance personnel are familiar with both the components and the techniques, the utilization costs per system are \$3.0 $\overline{M}$.

System α also uses state-of-the-art circuitry, gaining its increased performance by extending the components to their limits. It's acquisition cost is actually little more than that of system β, or \$1.4 $\overline{M}$.

Through pushing the state-of-the-art by introducing new techniques and components, system γ achieves the performance of system α and through redundancy and automatic fault location achieves the availability

of β. Other automation features overcome any negative effects of new techniques and utilization matches β also. But the acquisition costs including the burden of development costs amount to \$6 $\bar{M}$ per system. The additional training of personnel, the additional components to be supported, the additional weight, space and power requirements bring the cost of utilization up to \$8 $\bar{M}$.

From this type of cost effectiveness analysis it appears patent that system β buys more than α by a factor of two or promises two systems for each of system α and buys more than system γ by a factor of three - or three for every system γ. This is a most attractive situation - except - what happens to any forward progress or increase in our defense capability?

Two important factors have been overlooked. One is in the systems effectiveness calculation and the other in the cost effectiveness expression. Intelligence information indicates that the threat, if it is to be successfully countered, establishes a threshold for P. Anything less than a value of 850 will not successfully complete the mission. As a result, system β must be rejected despite its dollar attractiveness. It is also conceivable that the term A could have a threshold value which might reject system α. However, a potential solution in this case might be to bring the overall value of A to above threshold by using two system redundance. This doesn't appear to be attractive on a cost effectiveness basis, however, because our E_c for α would become 31.1 as against 43.7 for γ.

Earlier I indicated that there was a significant difference between these two expressions for Cost Effectiveness, and that this

$$(1)\quad Ec = \frac{PAU}{C_a + C_u} \qquad\qquad Ec = W\,\frac{PAU}{C_a + C_u}$$

was in the term W, military worth.

In my presentation to the Aerospace Reliability and Maintainability Symposium, I defined W as being

$$(11)\quad W = \frac{(F_1\,w_1 + \ldots\ldots F_n\,w_n)}{n}$$

where F is the fraction of the system effort devoted to a given mission element w, the summation of $F_1 + \ldots\ldots F_n$ being unity. This operative was designed to cope with the problem of variances among multimissioned systems having a common primary mission but with varying secondary missions. Prodded by Dr. Hitch in his address at the symposium, I realized that my expression of W was not complete. It has long been recognized that military worth degrades with time. However, it is not clear in just what manner this degradation occurs, except that it varies as a function of mission and as a function of the state-of-the-art -- more particularly the state-of-the-art as related to potential opposition. It may be linear in some cases, exponential in others or could be a rather unpredictable step function.

If we knew how to quantize exactly the term W, the solution would be more difficult in that we would then have to quantize the degradation factor exactly. Since we do not, we must express it in terms of a judgement index. This judgement index, as Dr. Alain Enthoven so cogently pointed out in a paper before the Naval War College, is not

purely intuitive but is premised on operational research analysis coupled with experience. It would appear then that a similar approach to the time degradation is no less valid. We know intuitively that military worth is real and that it degrades with time. Indeed one can readily envision a time threshold which must be met regardless of dollar costs.

I would therefore propose to introduce a new term to the expression to provide consideration of Time Effectiveness (E_t) defined as the index of degradation of military worth as a function of time. The value of this index should be established concomitantly with the index of military worth through gaming and other operational research techniques. Our expression for Cost Effectiveness (dollars) can remain unchanged but our expression for Cost Effectiveness or perhaps better identified as Defense Effectiveness E_d becomes

$$(12) \quad E_d = \frac{W}{E_t} \left(\frac{PAU}{Ca + Cu}\right)$$

Returning to our hypothetical case, were we to assume linearity of degradation of military worth with time, we might arrive at a scalar index with each 6 month period required to acquire being weighted as one in the index, we can deduce the following: since being identically missioned system α and γ can be considered to have equal values of W they can be considered to have a W of 1 and our expression becomes

$$E_d = \frac{1}{E_t}\left(\frac{PAU}{Ca + Cu}\right)$$

$$E_{d\alpha} = \frac{1}{9} \cdot 31.1 = 3.65$$

$$E_{d\gamma} = \frac{1}{14} \cdot 43.7 = 3.24$$

$$E_{d\alpha} = \frac{1}{14} \cdot 31.1 = 2.2$$

$$E_{d\gamma} = \frac{1}{18} \cdot 43.7 = 2.4$$

Fig #4

thus, if for example it would take $4\frac{1}{2}$ years to acquire system α and 7 years to acquire γ, the decision should appropriately be to elect system α since even buying two for one the $E_{d\alpha}$ is 3.65 where $E_{d\gamma}$ is 3.24. Whereas, if α required 7 years and γ 9 years, the decision would go to γ since $E_{d\gamma} = 2.4$ and $E_{d\alpha} = 2.2$.

You'll recall that in my opening remarks I stated that quantizing was conditional on when we learn how to do it. I'm not suggesting that I've learned. My intent is to express a concept for such an approach. The purpose of this clinic is to acquaint you with the Navy's needs. I used the "cutting tool" analogy previously. I'll conclude with it. We need to know how to put the proper edge on this promising tool to get a fine cut and a better product from our efforts in Defense Effectiveness.

SYSTEMS EFFECTIVENESS - NAVY

The term "Systems Effectiveness" is plagued, as most popularly-used conceptual terms, by a plethora of meanings In an effort to avoid adding to the confusion in this presentation, I shall define my terms in the context which they will be used by me.

By "Systems" I mean the total complex of men and machines required to carry out a military mission. These systems fall into one or the other of two broad classes --"Warfare" and "Support" systems. These in turn break down into two sub-classes: Warfare systems, Active or Passive and Support Systems, Direct or Indirect. By way of illustration, Warfare-Active would apply to SSBN. Warfare-Passive is illustrated by a mine defense system. The OMEGA navigational system is an example of Support-Direct while SPASUR is Support Indirect as is an ELINT system. The key to understanding this concept of system is illustrated by SSBN which includes not only the vehicle but POLARIS and the various other sub-systems involved in performing the SSBN mission together with the officers and men who go to make up the SSBN on station. Parenthetically I would add that this definition is not yet universally accepted in the Navy but the trend is in that direction.

The term "Systems Effectiveness" can then be defined as the probability that the system can successfully meet an operational demand throughout a given time period when operated under specified conditions.

This term can be expressed as

(1) $E = PAU$

Where P - Performance is a numerical index expressing system capability, assuming a hypothetical 100% availability, reliability and utilization of performance capability in actual operation.

A - Availability is the period or fraction of time that the system is ready and capable of fully performing its mission and

U - Utilization is the fraction of the performance capability actually utilized due to the specific application and the environment encountered.

Time does not permit giving you the complete rationale and derivation of this expression or the other mathematical expressions which I shall use. However, each of you has been provided with a copy of a paper entitled "Systems Effectiveness- a tool for appraisal" which does provide this background.

Continuing with the definitions, I would introduce the term "Cost Effectiveness" since Systems Effectiveness out of the context of Cost Effectiveness is a sterile academic exercise productive of little but to impress our fellows with our erudition. Simply defined, "Cost Effectiveness" is the ratio between Systems Effectiveness and its attendant costs. This can be expressed as :

$$(2)\ E_c = W\left(\frac{PAU}{C_a + C_u}\right)$$

Where W is the index of military worth of the mission of the system

P, A, and U are as previously defined.

C_a is the dollar cost of acquisition per system including its pro rata share of research and development costs and

C_u is the dollar cost of utilization or as it is som times referred

to cost of ownership.

The derivation of these latter two terms is included in the addenda sheet of the previously referenced paper.

There is yet another effectiveness term that I would introduce which I call Defense Effectiveness. This is differentiated from Cost Effectiveness, which is in terms of dollars, by the introduction of the considerations of time which is a cost element too frequently overlooked. The term Defense Effectiveness is probably best shown by its expression

$$(3) \quad E_d = \frac{W}{E_t} \left(\frac{PAU}{C_a + C_u} \right)$$

Where all of the other terms are as previously defined and E_t is the index of degradation of military worth as a function of time.

You will note that both W and E_t are indices which together form a co-efficient with which to numerically express the military judgment factor which Dr. Enthoven so clearly expressed in his paper before the Naval War College, Newport, as being a very necessary part of management decisions in military systems. There is admittedly a danger in the use of indices in that they can be used somewhat indiscriminately with grossly erroneous results. However, properly used they can be very effective tools.

My purpose in taking you on this little semantic excursion is to give you a feel for the context in which we in the Office of Naval Material use the term Systems Effectiveness. Only through this feel can one understand the objectives of our systems effectiveness effort. Before stating these, I would give you a bit more insight into our

concept of systems effectiveness by citing what we consider to be the elements which contribute to systems effectiveness.

These elements include reliability, maintainability, compatability, operability, human factors, design simplicity, logistics supportability, etc. Some additional feel for this aspect of Systems Effectiveness can be obtained from the remarks of RADM E. A. Ruckner at the recent Western States Navy R&D Clinic. Each of you has been provided a copy of his remarks.

Let us now turn to the objectives of our Systems Effectiveness Program. In a broad brush statement, it is to optimize Defense Effectiveness in all Navy systems. To this end we have a number of means. One of these is to develop methods for quantizing the elements of our generalized mathematical expressions and the elements of the expressions from which they were derived. This effort will include the development of weighting factors appropriate to the nature of the mission of the system being evaluated or appraised. For instance the weighting factors for reliability and maintainability will not be the same for a manned vehicle as they are for an unmanned vehicle.

A second objective, in the area of means, is to apply the developed numerical expressions to going systems projects to test their validity and refine them into a useable management tool rather than the conceptual expressions that they now are. From this point, we would apply them as a management tool for the appraisal of both plans and projects in execution. You will note that I have expressed but one end. The others are means. This shall be so for the remainder of this presentation.

We in ONM have but one objective which is an end and that is to provide a maximum Defense Effectiveness to the Navy. We will NOT strive for reliability for reliability's sake, maintainability for maintainability's sake or even low dollar costs solely for the sake of low dollar costs. All of the elements, even including Performance Capability, are tradeable items which can be supported ONLY insofar as they contribute to the maximization of the Defense Effectiveness index of each system.

Since these items are tradeable, we must have a medium of exchange for evaluating our tradeoffs. Numbers to assign to these elements therefore become imperative. They are needed not only as a method for appraisal in our own thinking but also as a medium for communicating our appraisals and management rationale to others. It is the recognition of this that has motivated us to attempt a generalized mathematical expression to provide a conceptual frame work within which we could examine the principal elements of performance, dollar costs, time and military worth and play them off one against the other to the end of maximizing Defense Effectiveness.

We in the Navy, have understood for some time that mathematical modeling is a powerful analytical tool. Our operational research people have used it extensively. Gaming and cueing theories have permitted examination of both strategic and tactical concepts without the tremendous expense of extensive exercises of ships, submarines and aircraft. Heretofore, we have lacked a generalized model with which to game our development and design concepts. The use of specific models has been attempted in the astronautics field with very promising results.

NASA particularly has been very successful in modeling their manned space systems. This kind of analysis, while expensive, is many orders of magnitude less expensive in both dollars and time than the "let's build one and try it" approach. It is felt that NASA's fine record of successful flights is attributable in no small measure to the careful analysis and mathematical modeling work done prior to hardware commitments. Indeed much of the Navy's success in POLARIS stems from the same kind of approach. Recognizing this we have pressed forward to achieve a means for applying this tool generally in Naval Development.

Who is this "we" that I've alluded to? What is the organization to implement this new approach in the Navy to Systems Effectiveness? At present, the overall organization is dominantly informal. However, there are formally organized pockets in various areas. The focal point in the Navy of the informal organization is the Systems Effectiveness Branch of the Systems Development Division of the Office of Naval Material. Under the leadership of RADM E. A Ruckner, the Deputy Chief of Naval Material for Development and the Chief of Naval Development and armed with a charter granted by VADM W. A. Schoech, the Chief of Naval Material, this small, tightly-knit group has the responsibility for developing the policies and procedures to insure that Systems Effectiveness is achieved by all the segments of the Naval Material Support Establishment which encompasses the four material bureaus and their field activities. Further this group reviews for Systems Effectiveness assurance all Technical Development Plans and Proposed Technical Approaches before they are submitted to the Chief of Naval Operations and the Secretarial levels.

At this juncture I would point out that a number of these documents, without which funds will not be allocated by the Office of the Director of Defense Research and Engineering, have been returned to their originators for rework because the Systems Effectiveness assurance part of the plans was not deemed adequate. This group is further supported by ghiter levels in the larger systems by DOD Directive 3200.9 which established Project Definition Phase for large systems. Each of you has been provided a copy of this directive together with the Navy Implementing Instruction which was written within this group.

I alluded earlier to organized pockets. Let me cite some of them. Rather than tc refer to the somewhat confusing code structure of the bureaus' organizations, I'll refer to them by project names. Again in the interest of time in this presentation, each of you has received a brochure for each of these projects from which you can obtain a greated depth of understanding of each of these projects. Lest I be accused of bias, I'll cite the projects in alphabetical order.

METRI "Military Essentiality Through Readiness Indices" is a project under the Bureau of Supplies and Accounts. This is a project for relating readiness of the fleet with its supporting items in simulated form to provide important decision-making information on problems of military essentiality and readiness. The ultimate objective is to get intelligence regarding; (a) the readiness of force units at any one time, (b) how readiness might be improved and (c) the extent that individual components affect readiness. Here we have in development one aspect of measurement to permit quantizing the elements of our

generaliz mathematical expression of Effectiveness.

PACED "Program for Advanced Concepts in Electornics Design" is a project under the Bureau of Ships with the Naval Applied Science Laboratory as the lead-laboratory. The thrust of this project is to develop measurement techniques and methodology for System Effectiveness analysis and appraisal with immediate reference to electronics systems and subsequent extrapolation to non-electronic syst ms.

SEAHAWK - The Advanced Design ASW Destroyer. This is a joint project between the Bureau of Ships and the Bureau of Naval Weapons. The thrust of the concept underlying this effort is the design of a total ship as an integrated system rather than the collecting together of a number of so-called systems into a common envelope called a ship. SEAHAWK together with a somewhat similar approach in submarines called FRISCO provide the vehicles for the PACED effort. These are an indication of the trend toward the larger concept of "System" that I alluded to earlier. SEAHAWK management is unique in that a voluntary joint BUSHIPS/BUWEPS Project Management Office was established to implement the system design concept well before the reorganization of the Navy Department.

VAST - "Versatile Avionics Shop Test" System is a Bureau of Naval Weapons project. This may be of somewhat more interest to the maintainability oriented members of the class. The VAST project addresses itself to the development of a standardized Avionic Shop for Aircraft Carriers having broad applicability to aircraft types with simplified operations and maintenance of the test set-up and reduced "turn-around" time for

the avionics portion of the aircraft.

These are six areas in the NMSE where organized efforts are being made and projects are going forward which have as their central theme the achievement of systems effectiveness. I alluded to them as pockets. They are pockets in the sense that they are organizationally isolated one from the other and, prior to the establishment of the Systems Effectiveness Branch in ONM, had no focal point for their efforts. They are not the only pockets. There are others.

I would remiss, if I confined myself to the NMSE alone. One very significant Navy effort toward achieving Systems Effectiveness is taking place outside of the NMSE. This is the program of the Office of the Chief of Naval Personnel referred to as the New Developments Human Factors Program. While this most important program, as indicated in the paper by Mr. William Hopkins which has been provided each of you, is being prosecuted by the BUPERS organization, it is not entirely outside of our Systems Effectiveness Group. As a part of our staff we have a full-time liaison officer from BuPers. Further, BuPers Human Factors teams are located within both the Bureau of Ships and the Bureau of Naval Weapons.

I would hope that none of you have any questions in your minds as to why I have included this effort in a discussion of Systems Effectiveness. If perchance you do let me explain. We are and have been living in an age of man-machine systems. Therefore man-effectiveness is every bit as important as machine effectiveness. Moreover, we must achieve a blending of the two in order to achieve maximum system effectiveness through optimum utilization of man vis-a-vis the machine

and vice versa.

You are going to see a greatly intensified emphasis of this in the very near future. We are quite aware that man reliability, man maintainability, man operability, and man supportability are explicitly factors which contribute to our generalized mathematical expression. As a matter of fact, our Systems Effectiveness Group has an Experimental Psychologist as a member in addition to the BuPers Liaison Officer. We in the NMSE do understand our Human Factors Engineering responsibilities in development. By "we" in this case I include our top people. By way of illustration, there is more than a little evidence that my selection as the Systems Effectiveness Branch Head was premised in large measure upon my training in psychology in addition to my engineering experience.

With the establishment of the Systems Effectiveness Branch about six months ago, there is a focal point for the informal organization. It is our intention to provide a cohesiveness to the Navy's Systems Effectiveness effort and to insure maximum cross-pollination among the various projects.

Somewhat inadequate staffing has hampered these efforts. The staffing situation stems from two sources. First, the usual problem of getting ceiling points allocated, in a climate in Washington of reducing numbers at the seat of the government, has been a factor. Perhaps the more significant factor has been the difficulty of finding the caliber of personnel which we feel is required to do the job properly. There are far too few of this type of people anywhere and many of them are either disenchanted with the rather frantic Washington working environment or

with the Civil Service pay scales. Nevertheless, under the persuasion that it is best to make haste slowly we feel confident that we'll resolve that staffing problem.

Our greater problem is one of education. This has several aspects. As a matter of fact, I am working at the resolution of one of them at this very moment. Too few working designers within and without government understand what we are trying to do and what their role is in relation to the whole. When one realizes just how many designers and engineers contribute to just one ship, one begins to appreciate the magnitude of the educational task ahead of us. The concepts which I expressed at the beginning of this presentation have not been taught in the Universities and generally are still not being taught. Further, Systems Effectiveness involves a degree of probabilistic thinking which only the very junior engineers have been appreciably exposed to in their education. Additionally, the probalistic reasoning involved in Systems Effectiveness is in a sense abhorent to the deterministic exactness which is the hallmark of the engineering profession.

But our educational problems are not all downward. Looking up we find people who are quite capable at probablistic thinking at the poker tables, the races or their brokers. Yet they have a moralistic block against extrapolating this kind of thinking to the job. The stigma of gambling concepts applied to their sense of responsibility is not tolerable. Yet--paradoxically--they glibly use the term "calculated risk". Perhaps if we can persuade them that we are trying to put real calculation into this term, we will go a long way in this educational effort.

To the solution of our educational problem, we, in the ONM Systems Effectiveness Group, are taking every opportunity to educate through professional symposia, courses such as this and the issuance of specification criteria and guidance handbooks. In your packets you have three such documents. BuWeps specifications WS 3250 and WR-30 and BuShips specification MIL-R-22732B(SHIPS). All three of these are in need of updating and--to some extent--clarification. But they are indicative of the work being done. In the Systems Effectiveness Branch we have a Technical Development Plan Handbook which we expect to promulgate later this calendar year which is intended to provide education and guidance in this area. NAVMAT NOTICE 3960, a copy of which has been provided to you, is an in-house attempt to provide education and guidance. This kind of documentation is most difficult to prepare. When dealing with concepts, the semantics problems of the written word become exterme. This is worsened when they are received with something less than complete enthusiasm by reason of their appearing to require additional work. And, indeed they do, at the outset. Homework has never been very attractive. In essence, we are requiring additional homework. The pay off, of course, is the final grade. -- And, I might add, a reduction in cramming. Nevertheless, we have experienced many situations which make it questionable whether or not people are truly trying to understand.

An addition to our educational problem is the fact of life situation that the operators are experiencing parallel difficulties in attempting to quantize their requirements so that a mathematical framework exists for the evaluation of Systems Effectiveness. Several terms in our Defense Effectiveness expression

$$E_d = \frac{W}{E_t}\left(\frac{PAU}{C_a + C_u}\right)$$

must come from the operators in their setting forth the operational requirement. The terms W & E_t must come from them. Threshold values for P and A must be established premised upon quantitative factors in the operational requirement. These have to be communicated through threat analysis and evaluation. Even as we have much to learn in quantizing our factors, the operational researchers are still groping for valid measures of their factors.

Despite these shortcomings in exactness, there is much that can be done. This is demonstrated by the projects I've cited. The house built out of rough hewn lumber offers a great deal of protection from the storm. We'd be stupid to stay out in the rain simply because our house isn't entirely leak proof. As we get better tools to work with, we'll get better fit and fewer leaks. In the meantime, we'll use the tools we have to get on with the job, and at the same time work at getting a better edge on our tools.

Unclassified
Security Classification

[redacted]

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Compiled by Systems Effectiveness Branch, Office of Naval Material Washington, D.C. 20360	Unclassified
	2b. GROUP --

3. REPORT TITLE

SYSTEMS EFFECTIVENESS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

--

5. AUTHOR(S) (First name, middle initial, last name)

Various

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1965	186	--

8a. CONTRACT OR GRANT NO --	9a. ORIGINATOR'S REPORT NUMBER(S) --
b. PROJECT NO. --	
c. --	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) --
d. --	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Hdqtrs. Naval Material Command (MAT 0325), Washington, D.C. 20360

13. ABSTRACT

This pamphlet was compiled to provide to personnel of the Naval Material Support Establishment (subsequently changed to Naval Material Command) a collection of papers which reflect the attitude and philosophy of the Chief of Naval Material towards various aspects of systems effectiveness. The compilation also provides a discussion of:

a. The planning, design, and cost considerations in systems development, and
b. Some techniques being utilized to realize the development of effective systems.

Most of the included papers were presented by the Chief of Naval Material and his representatives at the Northeastern States, Navy Research and Development Clinic held 18-20 November 1964 in Philadelphia. Also included, however, are several appropriate papers which were presented to other audiences.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification